AECOM Environment

Prepared for:
Eastman Chemical Company
Kingsport, TN

Prepared by:
AECOM
Chelmsford, MA
60322358.100
July 2014

# Site-Specific Dispersion Model for Eastman Chemical Company's Kingsport, TN Facility

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# Site-Specific Dispersion Model for Eastman Chemical Company's Kingsport, TN Facility

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Reviewed By Robert Paine

Quality

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# 1.0 Introduction

## 1.1 Background

Eastman Chemical Company ("Eastman") operates a large manufacturing facility ("Tennessee Operations) in Kingsport, Tennessee with coal-fired power generation. The terrain in this area features valleys and complex terrain ridges oriented WSW to ENE. A monitor in the vicinity of the Eastman manufacturing facility in Kingsport, Tennessee indicated attainment with the $SO_2$ National Ambient Air Quality Standards (NAAQS) until the promulgation of a much stricter 1-hour standard of 75 ppb in 2010. The area within 3 km of the facility has been included in a designated $SO_2$ nonattainment area[1].

In anticipation of the need to conduct a refined dispersion modeling analysis of their facility's $SO_2$ emissions, Eastman initiated a comprehensive meteorological and air quality monitoring study in 2012. The 1-year on-site database that was obtained has enabled Eastman and its consultant, AECOM, to develop a refined site-specific modeling approach with evaluation using concurrent meteorological, emissions, and monitoring data at multiple sites. This document describes the site-specific application of AERMOD that is proposed for modeling emissions from Eastman's Kingsport, TN facility.

## 1.2 Development of Site-Specific Dispersion Model for Kingsport, TN

The 1-year meteorological program, conducted from April 1, 2012 through March 31, 2013[2], involved a site-specific installation and operation of a 100-m tower and Doppler SODAR system to provide profiles of meteorological data as input to AERMOD for modeling the $SO_2$ emissions from the Eastman powerhouses. Eastman also collected $SO_2$ monitoring data in a network with multiple sites and archived hourly emissions data for the purpose of an analysis to verify the accuracy of the predictions of the United States Environmental Protection Agency (EPA) preferred model, AERMOD. AECOM found that AERMOD as run in default regulatory mode resulted in substantial over-predictions at the Eastman monitors.

AECOM proceeded to test AERMOD using the full year of on-site data with site-specific enhancements based upon featured derived from independent scientific research. These features include the following aspects:

- Use of low-wind speed options included in AERMET version 14134 (beta u* option),
- Use of minimum sigma-v specifications using the LOWWIND2 option in AERMOD, and
- Accounting for partial merging of buoyancy of plumes from adjacent stacks.

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[1] August 5, 2013 Federal Register notice, 78 FR 47191.

[2] The monitoring started in mid-March 2012 in a "shakedown" period, and final calibrations and shut down occurred in early June, 2013.

This report documents the 1-year database, the model evaluation procedures, the modeling options tested, and the results of the model evaluation. We conclude that the evaluation supports the use of the proposed site-specific model to assure future compliance with the 1-hour $SO_2$ NAAQS in Kingsport.

## 1.3 Organization of Report

Section 2 describes the Eastman Kingsport facility emission points in detail. It also discusses the emission controls that are being implemented to bring the area back into NAAQS attainment for $SO_2$. Section 3 describes the meteorological and monitoring field program between April 1, 2012 and March 31, 2013. Section 4 discusses how the meteorological data was processed for input to AERMOD. The evaluation procedures used to test dispersion model performance for AERMOD in default mode are presented in Section 5. A discussion of regional background concentrations is presented in Section 6. The performance evaluation of AERMOD in default mode for the full year of on-site data is presented in Section 7. Its poor performance provided insights for areas of improvement that led to the enhancements in the proposed site-specific model, whose formulation is described in Section 8. Section 9 presents the evaluation results of the site-specific modeling for comparison to the evaluation of the default model. Section 10 presents conclusions that the proposed site-specific model satisfies the conditions noted in Appendix W for adoption of an alternative model as proposed, and that this model should be approved by the Tennessee Department of Environmental Conservation (TDEC) and EPA for future applications with emissions from the Eastman Chemical Company facility in Kingsport, TN.

# 2.0 Eastman Chemical Company's Kingsport, TN Facility

## 2.1 Eastman Plant Setting

Eastman operates coal-fired boilers that constitute major $SO_2$ sources. The $SO_2$ emissions come from three main boiler groups that are shown in Figure 2-1: two B-83 stacks are about 70 m high, five B-253 stacks are about 76 m high, and the B-325 stack is about 114 m high.

Kingsport is located in the northeast corner of Tennessee, and shares an airport ("Tri-Cities") with regional cities of Johnson City and Bristol. This portion of Tennessee includes parts of three major geological formations: the Blue Ridge Mountains on the border with North Carolina in the east, the main Appalachian Mountains with the ridge and valley system (where Kingsport is located), and the Cumberland Plateau toward central Tennessee. The topography of the area is shown in Figure 2-2, which indicates that Kingsport is in a valley between ridges. The wind rose from the Tri-Cities airport, shown in Figure 2-3, reflects the general WSW-ENE alignment of the terrain features and the channeling of the winds accordingly. Figure 2-2 indicates that a prominent terrain feature to the west of Kingsport is Bays Mountain.

## 2.2 History of $SO_2$ Monitoring in Kingsport, TN

Before the 2012-2013 field study, historical $SO_2$ monitoring data had been taken from up to four stations, as shown in Figure 2-4. From that information, it was determined that the peak short-term monitored concentrations at the Ross N Robinson monitor were as high or higher than those at the other monitors, so that monitor was maintained to the present day while the others were eventually shut down. Until the 1-hour $SO_2$ NAAQS went into effect, the monitored concentrations indicated compliance with the pre-existing standards. However, due to the stringency of the new standard, the monitoring data now indicates concentrations that are above the 1-hour $SO_2$ NAAQS. The 2009-2011 $99^{th}$ percentile peak daily 1-hour maximum concentration, averaged over the 3 years (the "design concentration") is 196 ppb[3], which is about 2.6 times the NAAQS of 75 ppb.

## 2.3 $SO_2$ Emissions from Eastman Boiler Complexes

Each of the five stacks at the 253 Powerhouse serves identical boilers (Boilers 25 – 29, refer to Figure 2-1) which provide steam and electricity to the Tennessee Operations facility. These boilers, installed during the 1960s and 1970s, were designed as coal-fired boilers and are equipped with electrostatic precipitators for particulate matter control. Eastman is implementing a project to convert each of these to natural gas combustion, in conjunction with the State of Tennessee's State Implementation Plan for the Best Available Retrofit Technology (BART) implementation as part of the Regional Haze Rule

[3] As reported in EPA's Technical Support Document for the Tennessee nonattainment designations, available at http://www.epa.gov/air/sulfurdioxide/designations/tsd/04_TN_tsd.pdf

The stack at the 325 Powerhouse serves two coal-fired boilers, Boiler 30 and Boiler 31 and is modeled as a single emission source. Boiler 30 is equipped with a spray dryer absorber and electrostatic precipitator to control particulate matter and acid gases. Boiler 31 is equipped with a spray dryer absorber and fabric filter to control particulate matter and acid gases.

Stack B at the 83 Powerhouse serves five coal-fired boilers (Boilers 18 – 22) and Stack C serves two coal-fired boilers (Boilers 23 and 24). Hence two emission sources are modeled for the 83 Powerhouse. All of the 83 boilers are equipped with electrostatic precipitators for particulate matter control.

These fourteen boilers, along with three other backup natural gas fired boilers with minimal $SO_2$ emissions (B-423), provide process steam and most of the electrical power needed to operate Tennessee Operations. The combination of boilers and boiler operating loads at any given time depends on manufacturing demands along with availability of boilers as each boiler has annual scheduled shutdowns. Table 2-1 lists the locations (UTM, NAD27), annually averaged emission rates and stack parameters for the eight modeled emission sources.

**Figure 2-1: Power Houses at the Eastman Kingsport, TN Complex**

**Figure 2-2 Topographic Map of the Kingsport, TN Area**

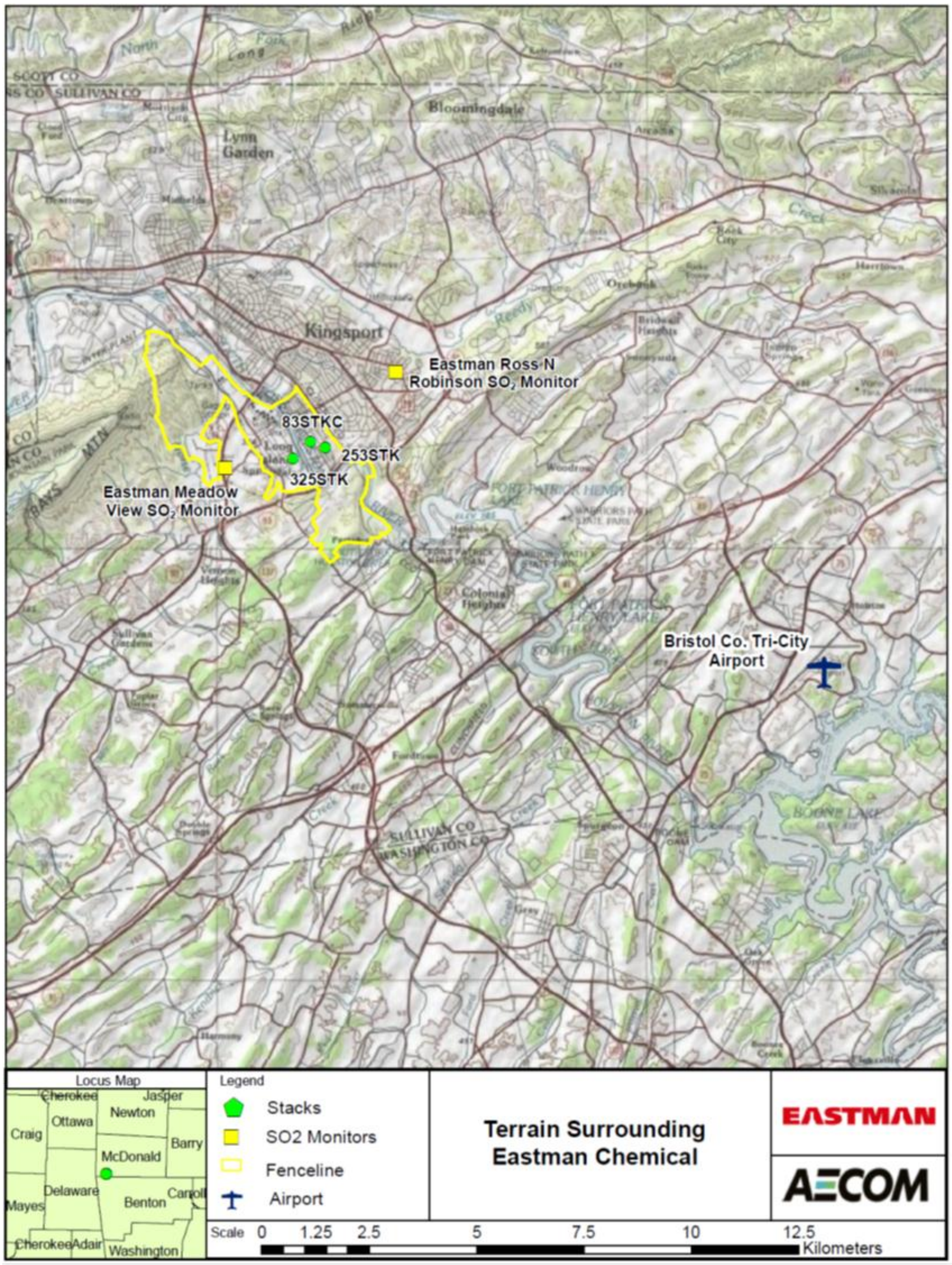


**Figure 2-3 5-Year Wind Rose from Tri-Cities Airport**

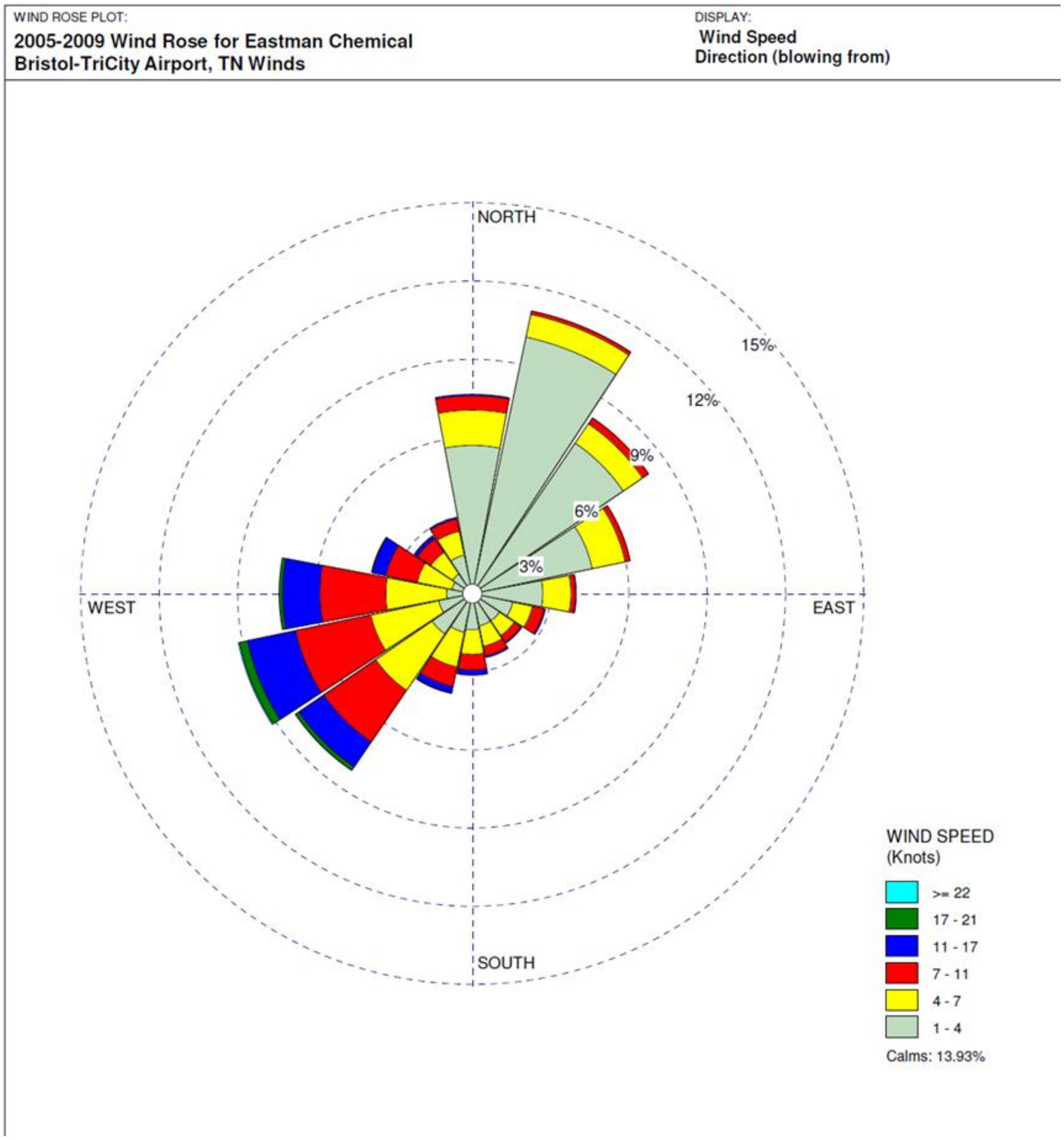


**Figure 2-4 Locations of Historical $SO_2$ Monitors Relative to the Eastman Plant**

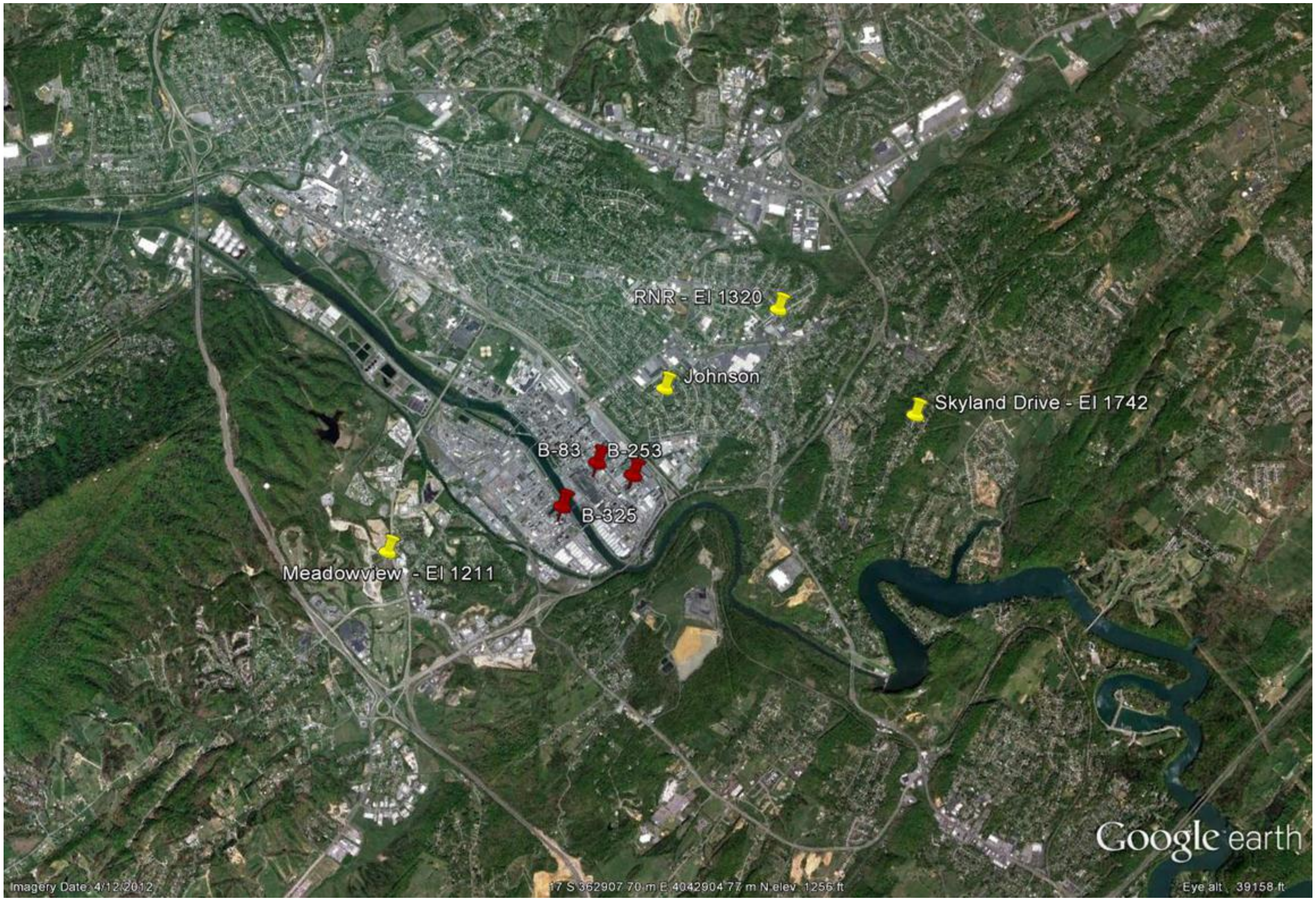


**Table 2-1: Eastman Chemical $SO_2$ Source Locations, Emissions and Stack Parameters**

| | | | | | | | Annually Averaged | | |
|---|---|---|---|---|---|---|---|---|---|
| Powerhouse | Stack(s) | UTM-X (m) | UTM-Y (m) | Base Elev. (m) | Stack Ht. (m) | Stack Diam. (m) | Emission Rate (g/s) | Stack Temp. (K) | Exit Velocity (m/s) |
| 83 | 18-22 | 362205.8 | 4042493.6 | 368.8 | 70.1 | 4.27 | 61.2 | 451.8 | 9.00 |
| | 23-24 | 362173.1 | 4042542.2 | 368.8 | 70.1 | 4.27 | 93.2 | 434.0 | 9.28 |
| 253 | 25 | 362515.1 | 4042333.2 | 373.7 | 76.2 | 2.44 | 83.4 | 397.6 | 17.52 |
| | 26 | 362530.1 | 4042342.0 | 373.7 | 76.2 | 2.44 | 86.1 | 392.6 | 18.41 |
| | 27 | 362544.7 | 4042351.8 | 373.7 | 76.2 | 2.44 | 86.4 | 406.6 | 17.72 |
| | 28 | 362557.8 | 4042361.0 | 373.7 | 76.2 | 2.44 | 84.7 | 404.7 | 17.43 |
| | 29 | 362571.5 | 4042370.6 | 373.7 | 76.2 | 2.44 | 85.8 | 408.6 | 18.25 |
| 325 | 30-31 | 361800.0 | 4042105.0 | 367.7 | 114.3 | 3.05 | 37.2 | 354.5 | 26.38 |

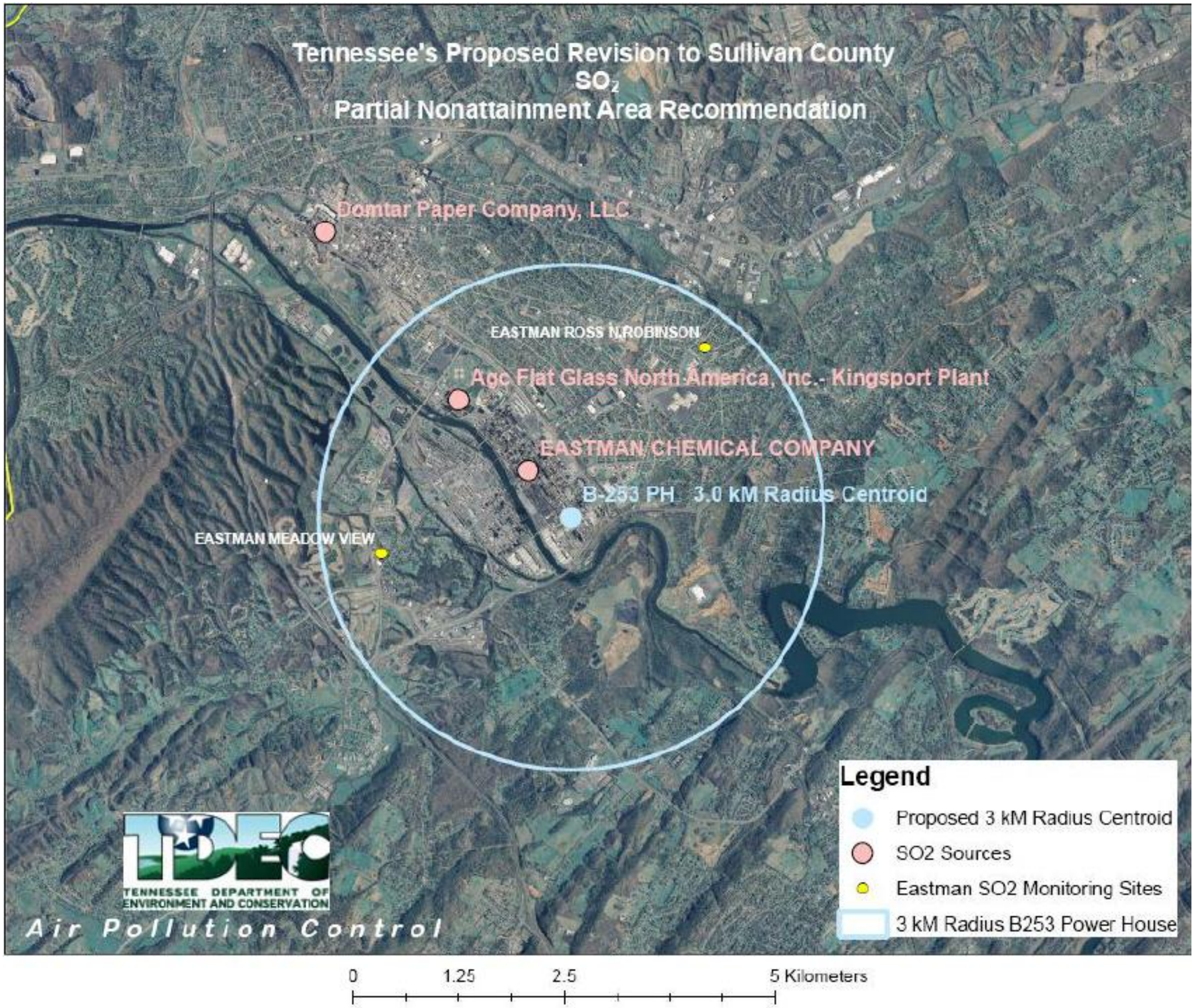
## 2.4 Regional $SO_2$ Emission Sources

EPA's final Technical Support Document[3] for the Tennessee nonattainment designations indicated that there are only two other $SO_2$ emission sources in the vicinity of the Eastman facility, as shown in Figure 2-5, and these two are less than 100 tons per year. Therefore, the regional $SO_2$ background in the vicinity of Kingsport is very low and there are no local sources identified by EPA that remain to be explicitly modeled.

## 2.5 Planned $SO_2$ Reductions at Eastman

Eastman is in the process of making reductions in $SO_2$ emissions at the Kingsport plant in accordance with BART requirements as well as the $SO_2$ nonattainment designation. The reductions involve a fuel switch from coal firing to natural gas firing at the B-253 boiler complex. This reduction is expected to reduce total plant $SO_2$ emissions to about 1/3 of the current levels. Due to the lack of regional $SO_2$ sources (and, thus a low background concentration, as noted by the monitoring), this reduction would be expected to result in a future monitored concentration that is below the NAAQS because the currently monitored design concentration is less than 3 times the NAAQS. However, the NAAQS is still quite stringent, such that a dispersion model that has an over-prediction bias could provide a false indication of a NAAQS violation. Therefore, Eastman has engaged in a comprehensive meteorological and air quality monitoring program to provide information for the purpose of using a dispersion model with an over-prediction bias that is lower than that of the default AERMOD model to demonstrate future NAAQS compliance in Kingsport. The field study used to support the site-specific dispersion model is described in the next section.

**Figure 2-5 EPA's Final Technical Support Document Depiction of Area $SO_2$ Sources Near Kingsport**



# 3.0 Full-Year Field Study to Support Site-Specific Model

## 3.1 Meteorological Monitoring Network Design

Eastman engaged AECOM to provide consulting advice to address the need for a site-specific database to support a dispersion model with relatively unbiased model predictions. AECOM determined from a review of the sources and topography in the area that EPA's guideline model, AERMOD[4], would likely be the first choice for the model to consider. Due to the complex terrain in the area, AECOM recommended that Eastman should acquire multiple-level meteorological data for input to AERMOD, based upon previous sensitivity studies[5] in terrain settings and EPA's use of site-specific data in its evaluation[6] of AERMOD. This general approach was first presented to TDEC and EPA Region IV in a meeting held in Atlanta on October 31, 2011.

The resulting plan for meteorological measurements led to the installation of a 100-meter meteorological tower equipped with multiple levels of meteorological sensors (at 2, 10, 50, and 100 m) and a SOund Detection And Ranging (SODAR) wind profiler system (with measurements starting at 50 m and extending upward in 50-m increments to 500 m). The data collected by these instruments was used as input to AERMOD, which was developed to accommodate multiple levels of meteorological data to more accurately predict vertical profiles of meteorological variables used in the modeling. For the monitoring program, the EPA Guidelines for Air Quality Modeling (40 CFR Part 51, Appendix W[7]) and EPA's meteorological monitoring guidance[8] provided the general guidance for sensor and parameter selection and siting of the tower and SODAR. For the $SO_2$ monitoring conducted in conjunction with this program, EPA's Quality Assurance Handbook for Air Pollution Measurement Systems[9] was followed.

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[4] Documentation for AERMOD is available at http://www.epa.gov/ttn/scram/dispersion_prefrec.htm#aermod.

[5] See, for example a study presented at the 2001 Air & Waste Management Specialty Conference: Paine, R.J., 2001. Meteorological Input Data for AERMOD Applications. Air & Waste Management Association Specialty Conference on Guideline on Air Quality Models: A New Beginning. Newport, Rhode Island. April, 2001

[6] This study is available at http://www.epa.gov/ttn/scram/7thconf/aermod/aermod_mep.pdf, and the supporting databases are available at http://www.epa.gov/ttn/scram/dispersion_prefrec.htm#aermod.

[7] Available at http://www.epa.gov/ttn/scram/guidance_permit.htm#appw.

[8] U.S. EPA. Meteorological Monitoring Guidance for Regulatory Modeling Applications. Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. EPA 454/R 99 005. February 2000. Available at http://www.epa.gov/scram001/guidance/met/mmgrma.pdf.

[9] The monitoring was conducted in accordance with the EPA guidance at the time, available at http://www.epa.gov/ttnamti1/archive/files/ambient/criteria/reldocs/4-87-007.pdf. This guidance was updated after the monitoring program ended; the 2013 guidance is available at http://www.epa.gov/ttnamti1/files/ambient/pm25/qa/QA-Handbook-Vol-II.pdf.

Eastman submitted a quality assurance plan for the meteorological monitoring to TDEC and EPA on January 5, 2012. Comments were received from both TDEC and EPA, and a revised (final) plan was submitted to the agencies on February 22, 2012 along with responses to comments received. No further agency comments were received, and the meteorological monitoring network went into operation officially on April 1, 2012 after a few days of “shakedown” operation.

Table 3-1 provides a list of the meteorological parameters included in the field study. As indicated in the monitoring plan reviewed by TDEC and EPA, input to AERMET consisted of parameters measured on the 100-m tower up to the 100-m level, and at incremental 50-m levels from 150 m to 500 m from the SODAR. SODAR data from the 50-m and 100-m levels were available for comparison to the tower data for quality assurance purposes. An independent audit of the meteorological measurements was conducted by Air Resources Specialists, Inc. in May, 2012. Their audit report, issued May 25, 2012, indicated that all meteorological instruments were within EPA-recommended accuracy goals, and that there were no adverse findings from the audit. Representatives of TDEC and EPA visited the monitoring network on December 11, 2012 and were escorted to the meteorological monitoring site as well as the $SO_2$ monitoring sites discussed in the next sub-section. Further updates regarding the site-specific measurement program were presented to TDEC and EPA on March 18, 2013. TDEC and EPA were advised in the December 2012 and March 2013 meetings that Eastman was testing site-specific modeling options and that the default AERMOD model showed significant over-predictions.

## 3.2 $SO_2$ Monitoring

During the April 1, 2012 – March 31, 2013 period of the meteorological measurement program, Eastman operated three $SO_2$ monitors for this full period (Ross N Robinson, Meadowview, and Skyland Drive – these were historical sites). Two other monitors were operated for a portion of this period (B-267 Parking Lot and Bays Mountain – these were new sites). Figure 3-1 provides a map showing the locations of the meteorological monitoring site as well as the $SO_2$ monitoring sites.

## 3.3 Meteorological Tower Data Capture Summary

The meteorological tower parameters generally had data captures above 90% for each month of the monitoring program. One exception is that for the months of July and August, 2012, data capture for precipitation was less than 90% due to a mechanical failure of the rain gauge. In December, 2012, foreign debris, i.e., vegetation, in the rain gauge also resulted in data capture below 90%. Each of the other months had data captures above 90% for precipitation, which was principally used to provide quality assurance for the SODAR data review.

The data capture for the April 2012-March 2013 measurement period for the meteorological tower parameters was above 90% (and often at 100%) for each parameter. Table 3-1 shows the data capture for all the parameters measured on the meteorological tower.

## 3.4 SODAR Data Capture Summary

AERMOD accepts data from multiple levels, and the measurement program was designed to accommodate the tower data with supplemental data from the SODAR. Data capture for the SODAR data was generally 90% or greater up to around 400 meters except for portions of the first quarter of 2013, as described further below. Table 3-2 shows the data capture for all the parameters measured by the SODAR.

**Figure 3-1: Locations of Meteorological Tower and SO2 Monitors**

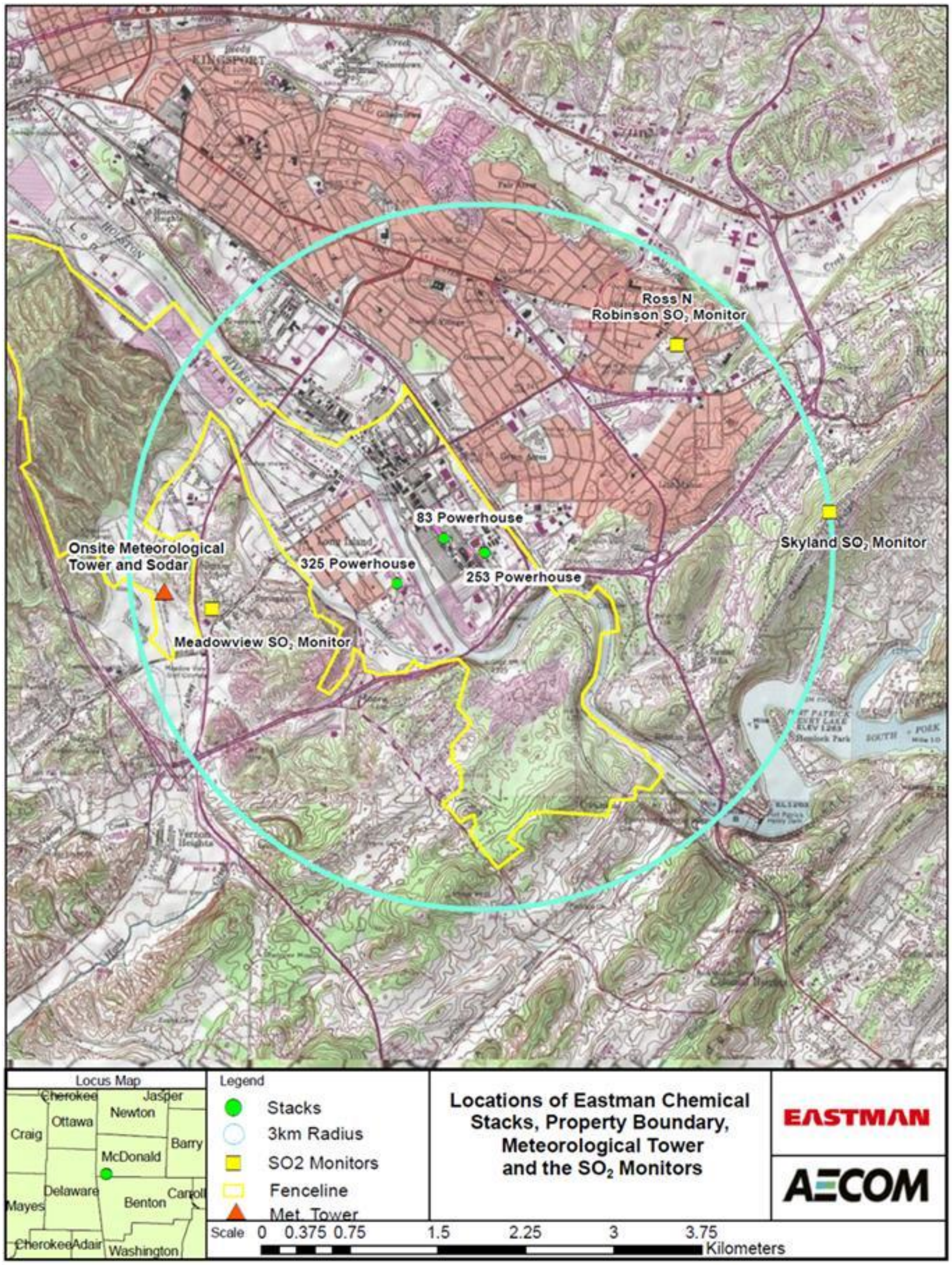

**Table 3-1: Data Capture for the Meteorological Tower; April, 2012 - March, 2013**

| Met Tower Level | Parameter | 1-Apr | May | Jun | 2nd Qtr | Jul | Aug | Sep | 3rd Qtr | Oct | Nov | Dec | 4th Qtr | Jan | Feb | Mar | 1st Qtr | Cum Avg. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2 Meter | 2M-Temp | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | **100** |
| | 2M- Tot Solar | 100 | 94 | 100 | **98** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | **100** |
| | 2M- RH | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | **100** |
| | 2M- Bar Press | 100 | 100 | 100 | **100** | 100 | 100 | 98 | **99** | 99 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | **100** |
| | 2M- Precip | 100 | 100 | 100 | **100** | 68 | 79 | 100 | **82** | 92 | 98 | 87 | **92** | 100 | 100 | 100 | **100** | **94** |
| 10 Meter | 10M- HWS | 99 | 100 | 100 | **100** | 100 | 100 | 99 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | **100** |
| | 10M- HWD | 99 | 100 | 100 | **100** | 100 | 100 | 99 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | **100** |
| | 10M- HWD SD1 | 99 | 100 | 100 | **100** | 100 | 100 | 99 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | **100** |
| | 10M- HWS SU | 99 | 100 | 100 | **100** | 100 | 100 | 99 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | **100** |
| | 10M- VWS | 99 | 100 | 100 | **100** | 100 | 100 | 99 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | **100** |
| | 10M- VWS Std | 99 | 100 | 100 | **100** | 100 | 100 | 99 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | **100** |
| | 10M- Temp | 100 | 100 | 100 | **100** | 100 | 100 | 99 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | **100** |
| | Delta T 2-10M | 100 | 100 | 100 | **100** | 100 | 100 | 99 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | **100** |
| 50 Meter | 50M- HWS | 99 | 100 | 100 | **100** | 100 | 100 | 99 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | **100** |
| | 50M- HWD | 99 | 100 | 100 | **100** | 100 | 100 | 99 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | **100** |
| | 50M- HWD SD1 | 99 | 100 | 100 | **100** | 100 | 100 | 99 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | **100** |
| | 50M- HWS SU | 99 | 100 | 100 | **100** | 100 | 100 | 99 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | **100** |
| | 50M- VWS | 99 | 100 | 100 | **100** | 100 | 100 | 99 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | **100** |
| | 50M- VWS Std | 99 | 100 | 100 | **100** | 100 | 100 | 99 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | **100** |
| | 50M- Temp | 99 | 100 | 100 | **100** | 100 | 100 | 99 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | **100** |
| | Delta T 10-50M | 100 | 100 | 100 | **100** | 100 | 100 | 99 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | **100** |

| Met Tower Level | Parameter | 1-Apr | May | Jun | 2nd Qtr | Jul | Aug | Sep | 3rd Qtr | Oct | Nov | Dec | 4th Qtr | Jan | Feb | Mar | 1st Qtr | Cum Avg. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 100 Meter | 100M-HWS | 99 | 100 | 100 | **100** | 100 | 100 | 99 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | **100** |
| | 100M-HWD | 99 | 100 | 100 | **100** | 100 | 100 | 99 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | **100** |
| | 100M-HWD SD1 | 99 | 100 | 100 | **100** | 100 | 100 | 99 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | **100** |
| | 100M-HWS SU | 99 | 100 | 100 | **100** | 100 | 100 | 99 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | **100** |
| | 100M-VWS | 99 | 100 | 100 | **100** | 100 | 100 | 99 | **100** | 100 | 100 | 100 | **100** | 95 | 93 | 100 | **96** | **99** |
| | 100M-VWS Std | 99 | 100 | 100 | **100** | 100 | 100 | 99 | **100** | 100 | 100 | 100 | **100** | 95 | 93 | 100 | **96** | **99** |
| | 100M-Temp | 99 | 100 | 100 | **100** | 100 | 100 | 99 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | **100** |
| | Delta T 10-100M | 100 | 100 | 100 | **100** | 100 | 100 | 99 | **100** | 100 | 100 | 100 | **100** | 100 | 100 | 100 | **100** | **100** |

**Table 3-2: Data Coverage for SODAR; April, 2012 - March, 2013**

| SODAR Level | Parameter | 1-Apr | May | Jun | 2nd Qtr | Jul | Aug | Sep | 3rd Qtr | Oct | Nov | Dec | 4th Qtr | Jan | Feb | Mar | 1st Qtr | Cum Avg. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 50 Meter | 50M- WSP | 87 | 99 | 100 | **95** | 98 | 99 | 97 | **98** | 91 | 91 | 98 | **93** | 85 | 40 | 89 | **71** | **90** |
| | 50M- WDR | 87 | 99 | 100 | **95** | 99 | 99 | 97 | **98** | 91 | 91 | 98 | **93** | 85 | 41 | 89 | **72** | **90** |
| | 50M- SD1 | 84 | 98 | 99 | **94** | 98 | 98 | 95 | **97** | 88 | 88 | 94 | **90** | 81 | 37 | 85 | **68** | **87** |
| | 50M- VWS | 86 | 99 | 100 | **95** | 99 | 99 | 97 | **98** | 91 | 92 | 98 | **94** | 85 | 42 | 89 | **72** | **90** |
| | 50M- SIG W | 84 | 98 | 99 | **94** | 98 | 98 | 96 | **97** | 88 | 89 | 94 | **90** | 81 | 38 | 86 | **68** | **87** |
| 100 Meter | 100M-WSP | 87 | 98 | 100 | **95** | 97 | 99 | 98 | **98** | 91 | 91 | 98 | **93** | 85 | 40 | 89 | **71** | **89** |
| | 100M-WDR | 88 | 98 | 100 | **95** | 97 | 99 | 98 | **98** | 91 | 93 | 98 | **94** | 85 | 42 | 89 | **72** | **90** |
| | 100M-SD1 | 83 | 97 | 99 | **93** | 97 | 98 | 97 | **97** | 90 | 89 | 95 | **91** | 83 | 38 | 86 | **69** | **88** |
| | 100M-VWS | 84 | 98 | 100 | **94** | 97 | 99 | 98 | **98** | 91 | 93 | 98 | **94** | 86 | 42 | 90 | **73** | **90** |
| | 100M- SIG W | 83 | 97 | 99 | **93** | 97 | 98 | 97 | **97** | 90 | 91 | 95 | **92** | 83 | 39 | 87 | **70** | **88** |
| 150 Meter | 150M-WSP | 86 | 99 | 100 | **95** | 98 | 99 | 98 | **98** | 91 | 91 | 98 | **93** | 85 | 37 | 88 | **70** | **89** |

| SODAR Level | Parameter | 1-Apr | May | Jun | 2nd Qtr | Jul | Aug | Sep | 3rd Qtr | Oct | Nov | Dec | 4th Qtr | Jan | Feb | Mar | 1st Qtr | Cum Avg. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 150M-WDR | 86 | 99 | 100 | **95** | 98 | 99 | 98 | **98** | 90 | 91 | 98 | **93** | 85 | 38 | 88 | **70** | **89** |
| | 150M-SD1 | 71 | 98 | 100 | **90** | 98 | 98 | 96 | **97** | 90 | 89 | 94 | **91** | 83 | 27 | 83 | **64** | **86** |
| | 150M-VWS | 73 | 99 | 100 | **91** | 98 | 99 | 98 | **98** | 91 | 92 | 97 | **93** | 85 | 35 | 87 | **69** | **88** |
| | 150M- SIG W | 71 | 98 | 100 | **90** | 98 | 99 | 97 | **98** | 90 | 90 | 94 | **91** | 83 | 29 | 84 | **65** | **86** |
| 200 Meter | 200M-WSP | 83 | 99 | 99 | **94** | 98 | 98 | 97 | **98** | 90 | 90 | 96 | **92** | 85 | 30 | 85 | **67** | **88** |
| | 200M-WDR | 83 | 99 | 99 | **94** | 98 | 98 | 97 | **98** | 90 | 90 | 96 | **92** | 85 | 31 | 85 | **67** | **88** |
| | 200M-SD1 | 65 | 98 | 99 | **87** | 97 | 98 | 96 | **97** | 90 | 88 | 93 | **90** | 83 | 21 | 81 | **62** | **84** |
| | 200M-VWS | 67 | 99 | 99 | **88** | 98 | 98 | 98 | **98** | 90 | 91 | 96 | **92** | 84 | 27 | 83 | **65** | **86** |
| | 200M- SIG W | 65 | 98 | 99 | **87** | 97 | 98 | 97 | **97** | 90 | 90 | 93 | **91** | 83 | 22 | 81 | **62** | **84** |
| 250 Meter | 250M-WSP | 80 | 98 | 99 | **92** | 97 | 98 | 97 | **97** | 90 | 85 | 95 | **90** | 84 | 24 | 84 | **64** | **86** |
| | 250M-WDR | 80 | 98 | 99 | **92** | 97 | 98 | 97 | **97** | 90 | 85 | 95 | **90** | 84 | 26 | 84 | **65** | **86** |
| | 250M-SD1 | 60 | 98 | 99 | **86** | 97 | 98 | 96 | **97** | 89 | 84 | 91 | **88** | 82 | 17 | 78 | **59** | **82** |
| | 250M-VWS | 62 | 98 | 99 | **86** | 97 | 98 | 97 | **97** | 90 | 85 | 94 | **90** | 84 | 23 | 82 | **63** | **84** |
| | 250M- SIG W | 60 | 98 | 99 | **86** | 97 | 98 | 96 | **97** | 90 | 84 | 91 | **88** | 82 | 18 | 78 | **59** | **83** |
| 300 Meter | 300M-WSP | 79 | 98 | 99 | **92** | 96 | 98 | 96 | **97** | 89 | 84 | 95 | **89** | 84 | 19 | 77 | **60** | **85** |
| | 300M-WDR | 79 | 98 | 99 | **92** | 96 | 98 | 97 | **97** | 90 | 84 | 95 | **90** | 84 | 21 | 77 | **61** | **85** |
| | 300M-SD1 | 58 | 97 | 99 | **85** | 95 | 98 | 95 | **96** | 88 | 82 | 90 | **87** | 81 | 12 | 67 | **53** | **80** |
| | 300M-VWS | 59 | 98 | 99 | **85** | 96 | 98 | 97 | **97** | 89 | 83 | 92 | **88** | 83 | 17 | 70 | **57** | **82** |
| | 300M- SIG W | 58 | 97 | 99 | **85** | 95 | 98 | 96 | **96** | 89 | 82 | 90 | **87** | 81 | 13 | 67 | **54** | **80** |
| | | | | | | | | | | | | | | | | | | |
| 350 Meter | 350M-WSP | 75 | 97 | 98 | **90** | 95 | 98 | 96 | **96** | 89 | 82 | 93 | **88** | 83 | 18 | 72 | **58** | **83** |

| SODAR Level | Parameter | 1-Apr | May | Jun | 2nd Qtr | Jul | Aug | Sep | 3rd Qtr | Oct | Nov | Dec | 4th Qtr | Jan | Feb | Mar | 1st Qtr | Cum Avg. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 350M-WDR | 75 | 97 | 98 | **90** | 95 | 98 | 96 | **96** | 90 | 82 | 93 | **88** | 83 | 18 | 72 | **58** | **83** |
| | 350M-SD1 | 55 | 97 | 98 | **83** | 95 | 97 | 95 | **96** | 87 | 80 | 89 | **85** | 79 | 9 | 59 | **49** | **78** |
| | 350M-VWS | 56 | 97 | 98 | **84** | 95 | 98 | 96 | **96** | 88 | 81 | 91 | **87** | 82 | 14 | 62 | **53** | **80** |
| | 350M- SIG W | 55 | 97 | 98 | **83** | 95 | 97 | 95 | **96** | 88 | 80 | 89 | **86** | 79 | 9 | 60 | **49** | **79** |
| 400 Meter | 400M-WSP | 63 | 97 | 99 | **86** | 95 | 98 | 95 | **96** | 88 | 80 | 90 | **86** | 83 | 15 | 69 | **56** | **81** |
| | 400M-WDR | 63 | 97 | 99 | **86** | 95 | 98 | 96 | **96** | 89 | 80 | 90 | **86** | 83 | 16 | 69 | **56** | **81** |
| | 400M-SD1 | 52 | 97 | 98 | **82** | 93 | 97 | 94 | **95** | 87 | 78 | 87 | **84** | 77 | 8 | 53 | **46** | **77** |
| | 400M-VWS | 53 | 97 | 98 | **83** | 94 | 97 | 95 | **95** | 88 | 79 | 89 | **85** | 80 | 11 | 57 | **49** | **78** |
| | 400M- SIG W | 52 | 97 | 98 | **82** | 93 | 97 | 95 | **95** | 87 | 78 | 87 | **84** | 77 | 8 | 53 | **46** | **77** |
| 450 Meter | 450M-WSP | 52 | 97 | 99 | **83** | 94 | 97 | 93 | **95** | 86 | 73 | 88 | **82** | 80 | 14 | 63 | **52** | **78** |
| | 450M-WDR | 52 | 97 | 99 | **83** | 94 | 97 | 95 | **95** | 88 | 80 | 88 | **85** | 80 | 14 | 63 | **52** | **79** |
| | 450M-SD1 | 46 | 97 | 98 | **80** | 92 | 95 | 92 | **93** | 84 | 69 | 83 | **79** | 76 | 6 | 42 | **41** | **73** |
| | 450M-VWS | 47 | 97 | 98 | **81** | 93 | 96 | 93 | **94** | 85 | 71 | 86 | **81** | 78 | 11 | 44 | **44** | **75** |
| | 450M- SIG W | 46 | 97 | 98 | **80** | 92 | 95 | 92 | **93** | 84 | 69 | 83 | **79** | 76 | 7 | 41 | **41** | **73** |
| 500 Meter | 500M-WSP | 52 | 96 | 98 | **82** | 92 | 95 | 90 | **92** | 78 | 74 | 82 | **78** | 76 | 9 | 42 | **42** | **74** |
| | 500M-WDR | 52 | 96 | 98 | **82** | 92 | 95 | 92 | **93** | 85 | 74 | 82 | **80** | 76 | 8 | 42 | **42** | **74** |
| | 500M-SD1 | 45 | 95 | 98 | **79** | 90 | 93 | 87 | **90** | 75 | 71 | 77 | **74** | 72 | 3 | 28 | **34** | **70** |
| | 500M-VWS | 46 | 95 | 98 | **80** | 91 | 94 | 89 | **91** | 77 | 75 | 80 | **77** | 73 | 6 | 29 | **36** | **71** |
| | 500M- SIG W | 45 | 95 | 98 | **79** | 90 | 93 | 88 | **90** | 76 | 73 | 77 | **75** | 72 | 3 | 27 | **34** | **70** |

The SODAR data capture was reduced (lower range of values) during certain portions of the measurement period due to natural events and noise interference issues. In the middle of April, 2012, a severe rain event damaged the system, resulting in data captures below 90% for the month. Components of the SODAR system were replaced on April 19, which resulted in a marked improvement in the data capture for each parameter. Other periods during portions of January-February 2013 had some reductions in data capture attributed to new building construction in the area, likely causing noise interference. This issue was finally resolved in early March 2013 by a combination of rotating the SODAR antenna table and other system adjustments.

## 3.5 Total System Data Capture

The 2012 monitoring plan reviewed by TDEC and EPA Region 4 had the following language to describe the acceptability of each hour's meteorological data for modeling purposes:

"The following criteria will be applied to determine whether an hour of the on-site data is counted as available for purpose of data capture:

- Wind direction, wind speed, and temperature must each be available for a given hour. These variables are used in the meteorological pre-processor to compute the atmospheric stability and other related micrometeorological parameters.
- Each of these parameters must be present from at least one of the three tower levels (10, 50, or 100 meters) or from the 50-m and/or 100-m SODAR levels; they need not be all present from the same level.
- If the SODAR is reporting missing data, but at least one tower level is reporting, then that hour is still acceptable."

Based upon these criteria, the meteorological monitoring program has easily met the 90% data availability for modeling purposes, as shown in Table 3-3. In fact, the meteorological tower had 3 levels of wind and temperature available nearly 100% of the time, and had supplemental SODAR data at four additional levels (up to 300 m) at least 85% of the time. Given the completeness of the meteorological tower data, the overall data coverage for the weather station was at or near 99+% per quarter for the meteorological parameters processed for the AERMOD modeling. Data from the 50-m and 100-m levels of the SODAR were not used in the modeling, but were used in performance testing of the SODAR against the meteorological tower.

**Table 3-3: Overall Data Capture Summary by Quarter for Model Input with Onsite Meteorological Data**

| | **Apr[1] 2012** | **May 2012** | **Jun 2012** | **1st Qtr** | **Jul 2012** | **Aug 2012** | **Sep 2012** | **2rd Qtr** |
|---|---|---|---|---|---|---|---|---|
| % hours with data available for modeling | 99.8 | 100.0 | 100.0 | 99.9 | 100.0 | 100.0 | 99.8 | 99.9 |

| | **Oct 2012** | **Nov 2012** | **Dec 2012** | **3th Qtr** | **Jan 2013** | **Feb 2013** | **Mar 2013** | **4th Qtr** | **Cum Avg.** |
|---|---|---|---|---|---|---|---|---|---|
| % hours with data available for modeling | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

Note: only four hours were missing over the entire year (two hours each in April and September, 2012) due to tower calibration activities.

# 4.0 Processing of Site-Specific Meteorological Data for AERMET

## 4.1 Field Data Used for AERMOD Evaluation

To prepare the on-site meteorological data for model input, the raw data needed to be extracted and formatted for use in the AERMET (version 14134) pre-processor. There are two separate sets of data. Meteorological measurements taken at the 100-m tower were made at 4 levels: 2 m, 10 m, 50 m, and 100 m. A nearby SODAR collected upper level data at 50-m increments up to the 500-700 m range. For the modeling, validated hourly[10] data were used from the SODAR from the 150-m level up to the 700-m level[11]. The sparseness of data above 700 m restricted its use in the modeling.

For wind data, the 1-minute-averaged winds from the tower at the 10-m, 50-m, and 100-m levels were extracted for use in the “AERMINUTE-all” preprocessor written for this project in order to provide an averaging procedure consistent with EPA’s AERMINUTE meteorological processor. AERMINUTE-all is an AECOM-modified version of the EPA’s AERMINUTE program, which uses National Weather Service (NWS) Automated Surface Observing System (ASOS) station data to calculate the hourly wind data based on the ASOS 1-minute data. However, since the ASOS stations’ minute data is in fact recorded as a 2-minute running average, AERMINUTE takes every other minute’s values to use in the hourly averages, thus limiting the maximum number of valid records per hour to 30. Since this 2-minute running average issue does not exist in the on-site data, AERMINUTE-all uses all (up to 60) of the valid, non-calm minute averages in the hourly calculations. The hourly-averaged wind data for these levels is used as a QA check to assess the performance of the averaging conducted in AERMINUTE-all.

For modeling purposes, no replacements of calms were done on the meteorological tower winds that recorded speeds below the wind vane starting threshold level of 1 mph. The AERMET and AERMINUTE-all processor take into account winds that are below a threshold value consistent with the instrument characteristics. For values of the standard deviation of vertical velocity (sigma-w) that were below ta value of 0.1 m/s, those values were set to missing[12].

Table 4-1 summarizes the data needed for the AERMOD model as well as the averaging period for each variable. Figure 4-1 details the processing of the raw data into AERMOD-ready surface and upper-air files. A more technical description of the procedures used as well as the AECOM-developed software for expediting the data pre-processing can be found in the modeling archive.

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[10] Starting in September 2012, 15-minute sub-hourly data were also collected for a few months.

[11] After the change in September, 2012 to sub-hourly data, SODAR data was archived up to the 500-m level.

[12] The starting speed of the vertical wind vane was 0.3 m/s. As per guidance in the SCIPUFF Technical Documentation, 2008. “A typical value for the vertical velocity variance, (sigma-w)^2, is 0.01$m^2s^{-2}$ and a typical vertical length scale, lambda-V, is 10m. We suggest using these values for all locations above the boundary layer." This implies a minimum sigma-w of 0.1 m/s. (p 194).

**Table 4-1: Raw On-site Data Used in the Modeling**

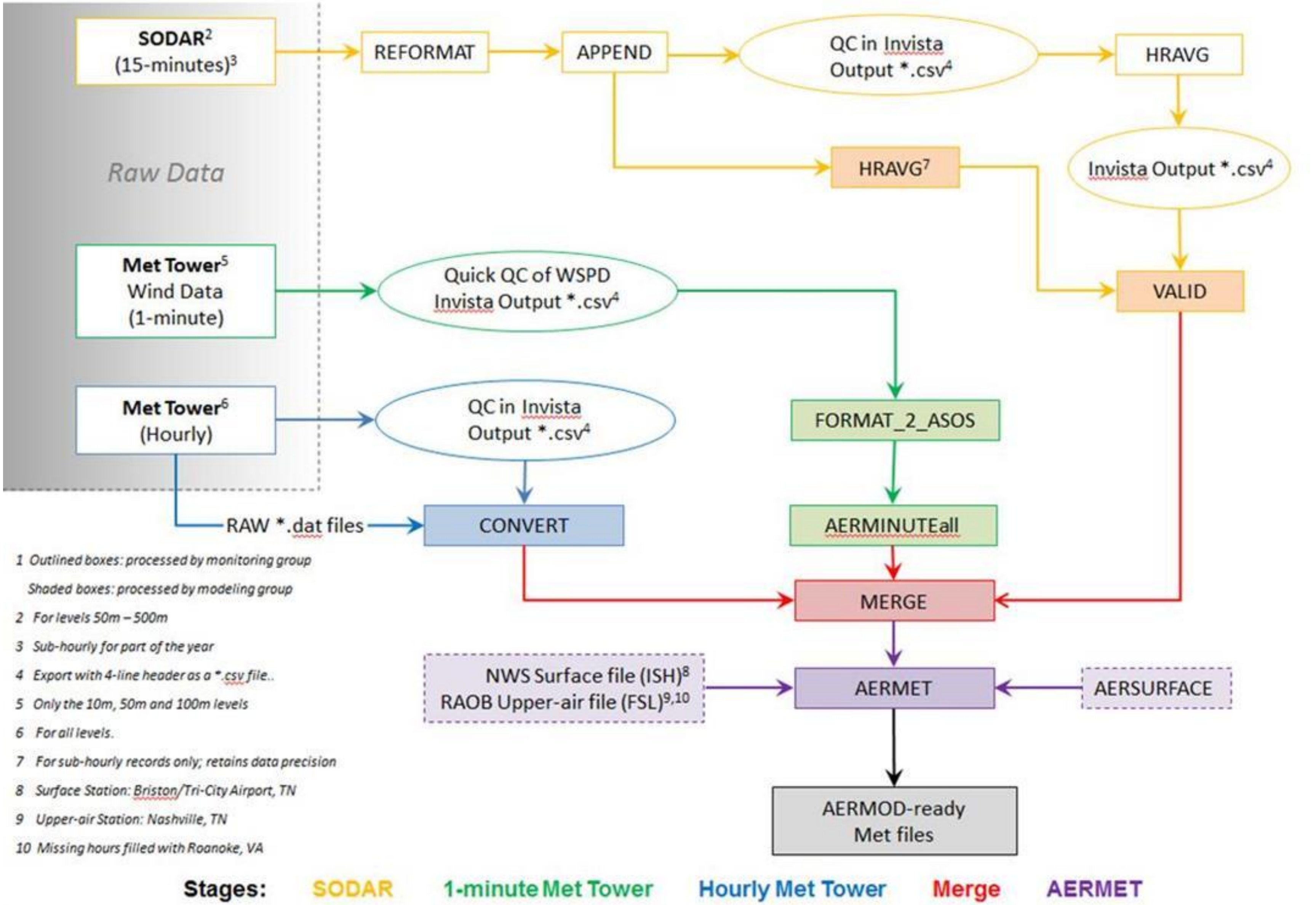
| Levels | MET TOWER: Hourly | | | | |
|---|---|---|---|---|---|
| 2 m | Pressure | Insolation | Temperature | | |
| 10, 50 and 100 m | Horiz. Wspd. | Wind Dir. | Sigma-theta | Sigma-w | Temp |
| | | | | | |
| **Levels** | **MET TOWER: Minute** | | | | |
| 10, 50 and 100 m | Horiz. Wspd. | Wind Dir. | | | |
| | | | | | |
| **Levels** | **SODAR: Sub-hourly & Hourly** | | | | |
| Every 50 m from 150 – 700 m | Horiz. Wspd. | Wind Dir. | Sigma-w | | |

## 4.2 Model Information

The air dispersion modeling was performed using EPA's preferred air dispersion model AERMOD (version 14134). AERMOD is a steady-state plume model that calculates air dispersion based on planetary boundary layer turbulence structure and scaling concepts. AERMOD is listed as a recommended model in Appendix W of 40 CFR Part 51 for determining compliance with National Ambient Air Quality Standards and other regulatory requirements. Supporting EPA processors utilized in this application include: the downwash processor BPIP (version 04274); the terrain processor AERMAP (version 11103); and the meteorological processors AERSURFACE (version 13016) and AERMET (version 14134).

The meteorological data reported by the 100-m tower are scalar averages, but those from the SODAR are vector averages. Due to the large percentage of hours for which SODAR data was available, the VECTORWS option was selected in AERMOD.

**Figure 4-1: On-site Data Processing Flowchart[1]**



## 4.3 Meteorological Processing: Surface Characteristics

A full year of the on-site meteorological data was processed with AERMET, the meteorological preprocessor for AERMOD, which is consistent with guidance stated in 9.3.1.2 of 40 CFR Part 51, Appendix W (EPA modeling guidelines). The meteorological data required for input to AERMOD was created with the latest version of AERMET (14134). AERMET creates two output files for input to AERMOD:

- SURFACE: a file with boundary layer parameters such as sensible heat flux, surface friction velocity, convective velocity scale, vertical potential temperature gradient in the 500-meter layer above the planetary boundary layer, and convective and mechanical mixing heights. Also provided are values of Monin-Obukhov length, surface roughness, albedo, Bowen ratio, wind speed, wind direction, temperature, and heights at which measurements were taken.

- PROFILE: a file containing multi-level meteorological data with wind speed, wind direction, temperature, sigma-theta ($\sigma_\theta$) and sigma-w ($\sigma_w$) when such data are available. For this application, the file contains data from several levels on the tower (2, 10, 50 and 100 m) and SODAR (from 150 m through 700 m, at 50-m increments).

AERMET requires specification of site characteristics including surface roughness ($z_o$), albedo (r), and Bowen ratio ($B_o$). These parameters were developed according to the guidance provided by EPA in the AERMOD Implementation Guide (AIG)[13].

The AIG provides the following recommendations for determining the site characteristics:

1. The determination of the surface roughness length should be based on an inverse distance weighted geometric mean for a default upwind distance of 1 kilometer relative to the measurement site. Surface roughness length may be varied by sector to account for variations in land cover near the measurement site; however, the sector widths should be no smaller than 30 degrees.

2. The determination of the Bowen ratio should be based on a simple un-weighted geometric mean (i.e., no direction or distance dependency) for a representative domain, with a default domain defined by a 10-km by 10-km region centered on the measurement site.

3. The determination of the albedo should be based on a simple un-weighted arithmetic mean (i.e., no direction or distance dependency) for the same representative domain as defined for Bowen ratio, with a default domain defined by a 10-km by 10-km region centered on the measurement site.

The AIG recommends that the surface characteristics be determined based on digitized land cover data. EPA has developed a tool called AERSURFACE that can be used to determine the site characteristics based on digitized land cover data in accordance with the recommendations from the

[13] Available in the AERMOD documentation at http://www.epa.gov/ttn/scram/dispersion_prefrec.htm#aermod.

AIG discussed above. AERSURFACE incorporates look-up tables of representative surface characteristic values by land cover category and seasonal category. AERSURFACE was applied with the instructions provided in the AERSURFACE User's Guide.

The latest version of AERSURFACE (Version 13016) supports the use of land cover data from the USGS National Land Cover Data 1992 archives[14] (NLCD92). The NLCD92 archive provides data at a spatial resolution of 30 meters based upon a 21-category classification scheme applied over the continental U.S. The AIG recommends that the surface characteristics be determined based on the land use surrounding the site where the surface meteorological data were collected.

As recommended in the AIG for surface roughness, the 1-km radius circular area centered at the meteorological station site was divided into 12 sectors for this analysis (see Figure 4-2).

In AERSURFACE, the various land cover categories are linked to a set of seasonal surface characteristics. As such, AERSURFACE requires specification of the seasonal category for each month of the year. The following five seasonal categories are supported by AERSURFACE, with the applicable months of the year specified for this site.

1. Midsummer with lush vegetation (June-August).
2. Autumn with un-harvested cropland (September- November).
3. Late autumn after frost and harvest, or winter with no snow (December, January, and February).
4. Winter with continuous snow on ground (none; based on the Tri-City Regional Airport record for April, 2012 – March, 2013).
5. Transitional spring with partial green coverage or short annuals (March-May).

For Bowen ratio, the land use values are linked to three categories of surface moisture corresponding to average, wet, and dry conditions. The surface moisture condition for the site may vary depending on the meteorological data period for which the surface characteristics will be applied. AERSURFACE applies the surface moisture condition for the entire data period. Therefore, if the surface moisture condition varies significantly across the data period, then AERSURFACE can be applied multiple times to account for those variations. As recommended in the AERSURFACE User's Guide, the surface moisture condition for each month was determined by comparing the on-site precipitation for the period of data to be processed to the 30-year climatological record (Tri-City Regional Airport), selecting "wet" conditions if precipitation is in the upper 30$^{th}$ percentile, "dry" conditions if precipitation is in the lower 30$^{th}$ percentile, and "average" conditions if precipitation is in the middle 40$^{th}$ percentile. The 30-year precipitation data set used in this modeling was taken from the National Climatic Data Center. The monthly designations of surface moisture input to AERSURFACE are summarized in Table 4-1.

[14] http://edcftp.cr.usgs.gov/pub/data/landcover/states/

**Table 4-2: Bowen Ratio Categories for the On-site Meteorological Tower**

| Month | Bowen Ratio Category | |
|---|---|---|
| | 2012 | 2013 |
| April | Average | -- |
| May | Dry | -- |
| June | Dry | -- |
| July | Wet | -- |
| August | Dry | -- |
| September | Wet | -- |
| October | Average | -- |
| November | Dry | -- |
| December | Dry | -- |
| January | -- | Wet |
| February | -- | Dry |
| March | -- | Average |

## 4.4 Meteorological Processing: AERMET

The processed on-site 12-level meteorological data for the merged meteorological tower (levels: 2 m, 10 m, 50 m and 100 m) and SODAR (levels: 150 m – 500 m, at 50-m increments) was entered into the stage 1 AERMET input file along with concurrent NWS surface data from the Tri-City Regional Airport National Weather Station (13877) and upper air data from Nashville, TN (13897).

The Tri-City Regional Airport is located approximately 8.5 miles east, southeast of the facility. Integrated Surface Hourly (ISH) surface data in for the April, 2012 – March, 2013 period were downloaded from the National Climate Data Center (NCDC)[15]. The Nashville airport is located 200 miles west of Kingsport and has mean mixing heights that are comparable to this location. Upper air data was downloaded from the NOAA radiosonde observation (RAOB) website[16]. Three missing upper air 12Z hours were filled with concurrent data from the nearby Roanoke, VA upper air station (noted in a README file in the accompanying modeling archive).

The meteorological data was processed using the AERMOD meteorological preprocessor AERMET (version 14134).

The threshold wind speed for the on-site data was set at 0.44704 m/s (1 mph). In the stage 3 input, no NWS substitutions were performed for any hours with missing on-site wind data (which was not an issue given the high data coverage of the meteorological tower). Two sets of meteorological data were produced. For the default AERMET/AERMOD testing, AERMET was processed with no special option (aside from VECTORWS mentioned in section 4.2).

For a sense of the bulk wind flow near plume height, the 100-m wind rose in Figure 4-3 shows the percentage of time wind blew from each direction for the April, 2012 through March, 2013 period.

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[15] ftp://ftp.ncdc.noaa.gov/pub/data/noaa

[16] http://www.esrl.noaa.gov/raobs/

**Figure 4-2: Land Use, 1 km Around On-site Meteorological Station from National Land Cover Dataset**

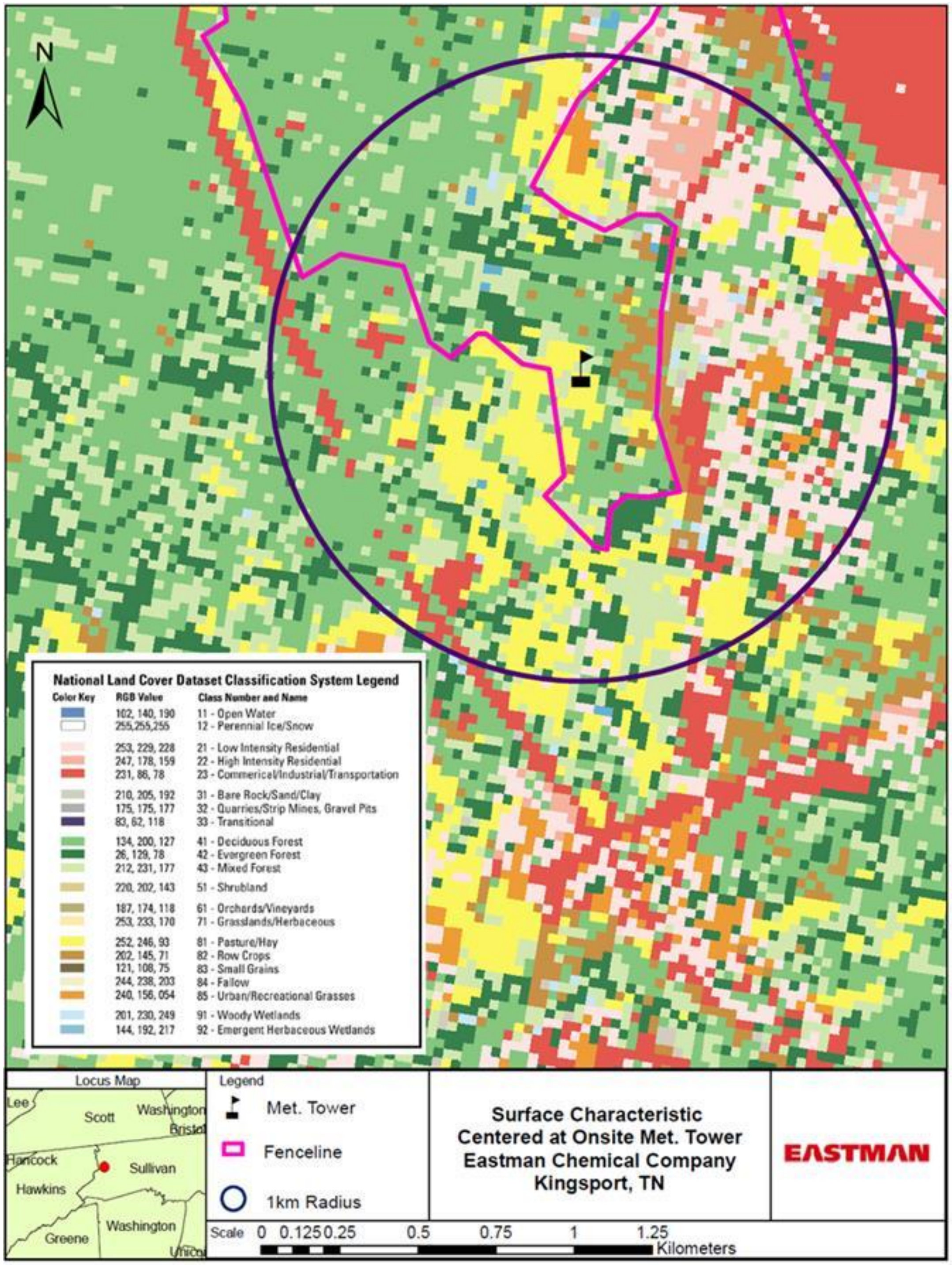
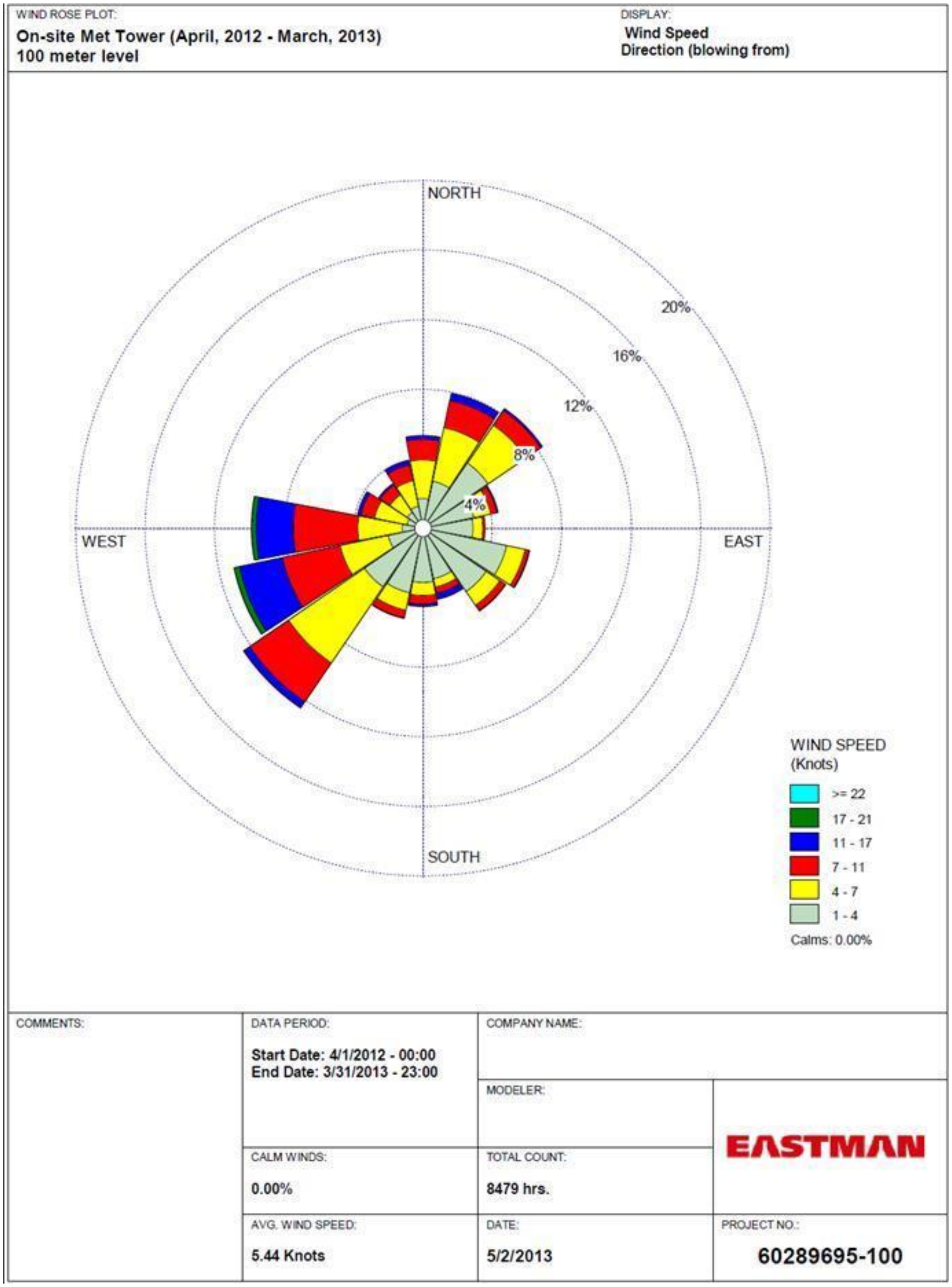


**Figure 4-3: Wind Rose for 100-m On-site Meteorological Tower; Kingsport, TN**



# 5.0 Procedures for Model Evaluation

AERMOD was run with hourly emissions and exhaust parameter data supplied by Eastman and with the hourly meteorological data processed as described in Section 4. Initial modeling was conducted with default modeling options to determine whether AERMOD has relatively unbiased predictions at the three monitors that operated during the entire period of the meteorological monitoring program. Predictions were made at these three monitoring sites (Meadowview, Ross N. Robinson, and Skyland Drive) and were compared to observations using the evaluation metrics described below. These evaluation metrics were incorporated into presentations made to TDEC and EPA in December 2012 and March 2013.

## 5.1 Performance Evaluation Metrics Used

The model evaluation results are reported using metrics that address four basic areas.

- A key operational metric is tied to the form of the 1-hour $SO_2$ NAAQS is the "design concentration" (99$^{th}$ percentile of the peak daily 1-hour maximum values). This tabulated statistic was developed for the three monitors for the observations and model predictions at each individual monitor.

- Time series plots of the observed and predicted daily maximum 1-hour $SO_2$ concentrations were also developed; see Figure 7-5 for examples. While the tabulation of the design concentration provides a comparison of just one value for the predictions and observations, the time series plot provides a comparison for the entire period evaluated. The plots show the relative frequency and magnitude of the concentration predictions and observations. Our review of these plots result in somewhat qualitative, but informative, findings regarding the performance of each model and also present seasonal distributions of the concentration patterns for both observations and predictions.

- Operational performance of models for predicting compliance with air quality regulations, especially those involving a peak or near-peak value at some unspecified time and location, can be assessed with quantile-quantile (Q-Q) plots[17]. Q-Q plots (see figures in Section 7 for examples) are created by sorting by rank the predicted and the observed concentrations from a set of predictions initially paired in time and space. The sorted list of predicted concentrations is then plotted by rank against the observed concentrations, also sorted by rank. These concentration pairs are no longer paired in time, but we have retained the location pairing in this evaluation study. Such plots are useful for answering the question, "Over a period of time evaluated, does the distribution of the model predictions match those of observations?" Scatterplots, which use data paired in time, would provide a stricter test, answering the question: "At a given time and place, does the magnitude of the model prediction match the observation?" However, it is the experience of model developers[18,19] that wind direction uncertainties can and do

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[17] Chambers, J. M., Cleveland, W. S., Kleiner, B., and Tukey, P. A. 1983. Chapter 3: Comparing Data Distributions. Graphical Methods for Data Analysis. (Bell Laboratories). Wadsworth International Group and Duxbury Press.

[18] Weil J.C, Sykes and Venkatram A. 1992. Evaluating air-quality models: Review and outlook. J. Appl. Met., 31, p 1121-1144.

cause disappointing scatterplot results from what are otherwise well-performing dispersion models. Therefore, the Q-Q plot instead of the scatterplot is a more pragmatic procedure for demonstrating model performance of applied models. Venkatram[20] makes a cogent argument for the use of Q-Q plots for evaluating regulatory models. Quantile-quantile (Q-Q) plots of the ranked daily maximum 1-hour $SO_2$ concentrations for predictions and observations are useful. A "perfect" model would have all points on the central diagonal (45-degree) line.

- Lists of the meteorological conditions and hours/dates of the top several predictions and observations provide an indication as to whether these conditions are consistent between the model and monitoring data. For example, if the peak observed concentrations generally occur during daytime hours, we would expect that a well-performing model would indicate that the peak predictions are during the daytime as well. Another meteorological variable of interest is the wind speed magnitudes associated with observations and predictions. It would be expected, for example, that if the wind speeds associated with peak observations are low, then the modeled peak predicted hours would have the same characteristics.

## 5.2 Tolerance Range for Unbiased Model Results

One issue to keep in mind regarding $SO_2$ monitored observations, is that they can be biased up to 10% and be acceptable. This fact is related to the tolerance in the EPA procedures[21] associated with quality control checks and span checks. Therefore, even ignoring uncertainties in model input parameters that can also lead to modeling uncertainties, just the uncertainty in measurements indicate that modeled-to-monitored ratios between 0.9 and 1.1 should be considered as unbiased.

[19] Liu, M. K., and G. E. Moore. 1984. Diagnostic validation of plume models at a plains site. EPRI Report No. EA-3077, Research Project 1616-9, Electric Power Research Institute, Palo Alto, CA.

[20] Venkatram, A., R. W. Brode, A. J. Cimorelli, J. T. Lee, R. J. Paine, S. G. Perry, W. D. Peters, J. C. Weil, and R. B. Wilson. 2001. A complex terrain dispersion model for regulatory applications. *Atmos.Environ.,* 35, 4211-4221.

[21] Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II, Ambient Air Quality Monitoring Program, 2013, available at http://www.epa.gov/ttnamti1/files/ambient/pm25/qa/QA-Handbook-Vol-II.pdf. (Table 10-3 and Appendix D, page 13).

# 6.0 Determination of Background Concentrations

To account for the impact of sources other than Eastman, it is necessary to include the contributions of any identified nearby $SO_2$ sources as well as distant sources that would have a relatively uniform concentration impact over the nonattainment area. The discussion in Section 2.4 establishes that there are no nearby sources of $SO_2$ that should be included in the modeling.

The procedure we used to quantify the regional background concentration was to use data from the available Eastman monitors and to construct an hourly sequence of concentrations for an idealized background monitor that consists of the lowest concentration measured among the monitors for each hour. This step reduces the chances of double-counting the impacts from the Eastman sources and the monitor. However, a conservatively high background was selected from this hourly sequence by using the Tier 2 approach of the 99$^{th}$ percentile value by hour and season as described in the March 1, 2011 EPA guidance[22]. The seasonal by hour of the day ambient background value was processed within the model using the BACKGRND SEASHR keyword in the source card.

Additional filters on the data to set aside hours for which all monitors may have been impacted by Eastman plant emissions (due to stagnation or recirculation) were as follows:

- A downwind analysis of all meteorological levels up to 400 m was performed to eliminate plant impacts (wind directions within +/- 45 degrees of a monitor eliminated that monitor for the given hour).
- Rare hours with high impacts (> 30 $\mu g/m^3$) at all monitors were excluded from consideration for the 99$^{th}$ percentile background.
- After the downwind and high-impact considerations, the hourly values were screened for the lowest remaining observations among the valid monitor records for each hour.
- The method prescribed by the 2011 EPA guidance prescribes that for 1-hour $SO_2$, the 99$^{th}$ percentile for each season for each hour (i.e. the 2$^{nd}$ High) were selected for the lookup table.
- Hour 4 was typically a calibration hour in the monitoring network, so data from hours 3 and 5 were used to interpolate values for the lookup table.

Figure 6-1 shows the resultant seasonal values. Table 6-1 tabulates the same 96 values from Figure 6-1 for the modeling.

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[22] This guidance is available at http://www.epa.gov/ttn/scram/guidance/clarification/Additional_Clarifications_AppendixW_Hourly-NO2-NAAQS_FINAL_03-01-2011.pdf.

**Figure 6-1: Seasonal by Hour of Day Ambient Background Values for Kingsport**

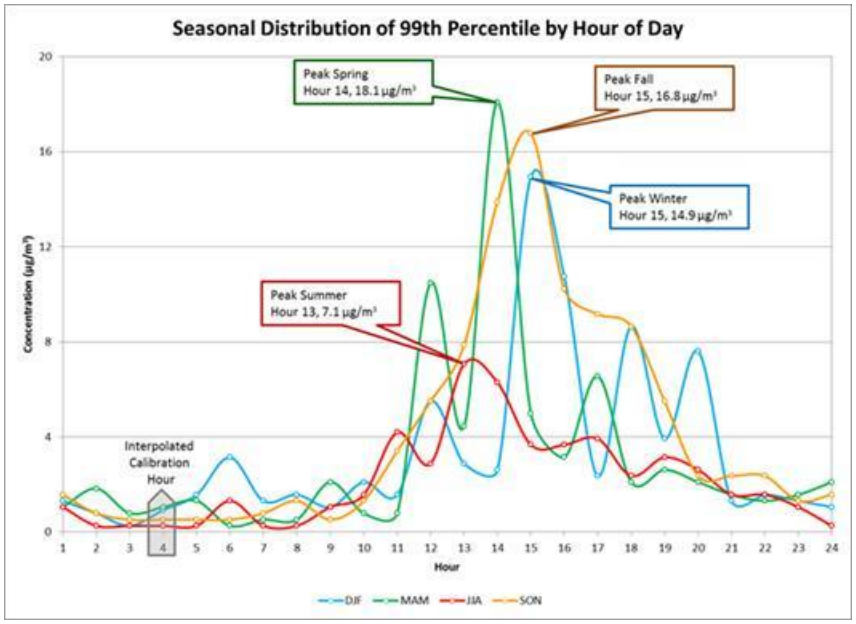



**Table 6-1: Lookup Table for Each Season by Hour of Day**

| Hour | DJF | MAM | JJA | SON |
|---|---|---|---|---|
| 1 | 1.31 | 1.05 | 1.05 | 1.57 |
| 2 | 0.79 | 1.83 | 0.26 | 0.79 |
| 3 | 0.26 | 0.79 | 0.26 | 0.52 |
| 4 | 0.92 | 1.05 | 0.26 | 0.52 |
| 5 | 1.57 | 1.31 | 0.26 | 0.52 |
| 6 | 3.14 | 0.26 | 1.31 | 0.52 |
| 7 | 1.31 | 0.52 | 0.26 | 0.79 |
| 8 | 1.57 | 0.52 | 0.26 | 1.31 |
| 9 | 1.05 | 2.1 | 1.05 | 0.52 |
| 10 | 2.1 | 0.79 | 1.57 | 1.31 |
| 11 | 1.57 | 0.79 | 4.19 | 3.41 |
| 12 | 5.5 | 10.48 | 2.88 | 5.5 |
| 13 | 2.88 | 4.45 | 7.07 | 7.86 |
| 14 | 2.62 | 18.08 | 6.29 | 13.89 |
| 15 | 14.93 | 4.98 | 3.67 | 16.77 |
| 16 | 10.74 | 3.14 | 3.67 | 10.22 |
| 17 | 2.36 | 6.55 | 3.93 | 9.17 |
| 18 | 8.65 | 2.1 | 2.36 | 8.65 |
| 19 | 3.93 | 2.62 | 3.14 | 5.5 |
| 20 | 7.6 | 2.1 | 2.62 | 2.36 |
| 21 | 1.31 | 1.57 | 1.57 | 2.36 |
| 22 | 1.57 | 1.31 | 1.57 | 2.36 |
| 23 | 1.31 | 1.57 | 1.05 | 1.31 |
| 24 | 1.05 | 2.1 | 0.26 | 1.57 |

# 7.0 Evaluation Results for Default AERMOD Model

AERMET/AERMOD version 14134 as run in regulatory default mode was evaluated with Eastman hourly $SO_2$ emissions and stack exhaust data for the period April 1, 2012 through March 31, 2013 for three monitoring sites: Ross N Robinson, Skyland Drive, and Meadowview. This section describes the processing of the receptor and building downwash information; the previous section detailed the processing of the on-site meteorological data. The results of the evaluation for the default AERMOD model are presented using the evaluation metrics described in Section 5.

## 7.1 Receptor Processing

The application of AERMOD requires characterization of the local (within 3 kilometers) dispersion environment as either urban or rural, based on an EPA-recommended procedure that characterizes an area by prevalent land use. This land use approach classifies an area according to 12 land use types. In this scheme, areas of industrial, commercial, and compact residential land use are designated urban. According to EPA modeling guidelines, if more than 50 percent of an area within a 3-km radius of the proposed facility is classified as rural, then rural dispersion coefficients are to be used in the dispersion modeling analysis. Conversely, if more than 50% of the area is urban, urban dispersion coefficients are used. Visual inspection of the 3-km area surrounding the Eastman facility location shows the area is rural (see Figure 7-1).

Model receptors were placed at the three monitoring locations. Terrain elevations were developed from the National Elevation Dataset (NED) acquired from USGS[23], using the EPA's terrain processor, AERMAP (version 11103).

[23] http://seamless.usgs.gov/index.php

**Figure 7-1: Aerial of 3-km Radius around the Facility Center of Eastman Chemical Company**

## 7.2 Building Downwash Processing

Good engineering practice (GEP) stack height is defined as the stack height necessary to ensure that emissions from the stack do not result in excessive concentrations of any air pollutant as a result of atmospheric downwash, wakes or eddy effects created by the source, nearby structures or terrain features.

A GEP stack height analysis was performed for the hazardous waste combustion unit stacks in accordance with EPA's stack height guidelines (EPA, 1985). Per the guidelines, the physical GEP height, ($H_{GEP}$), is determined from the dimensions of all buildings which are within the region of influence using the following equation:

$$H_{GEP} = H_B + 1.5L$$

where:

$H_B$ = height of the structure within 5L of the stack which maximizes $H_{GEP}$, and

L = lesser dimension (height or projected width) of the structure.

For a squat structure, i.e., height less than projected width, the formula reduces to:

$$H_{GEP} = 2.5H_B$$

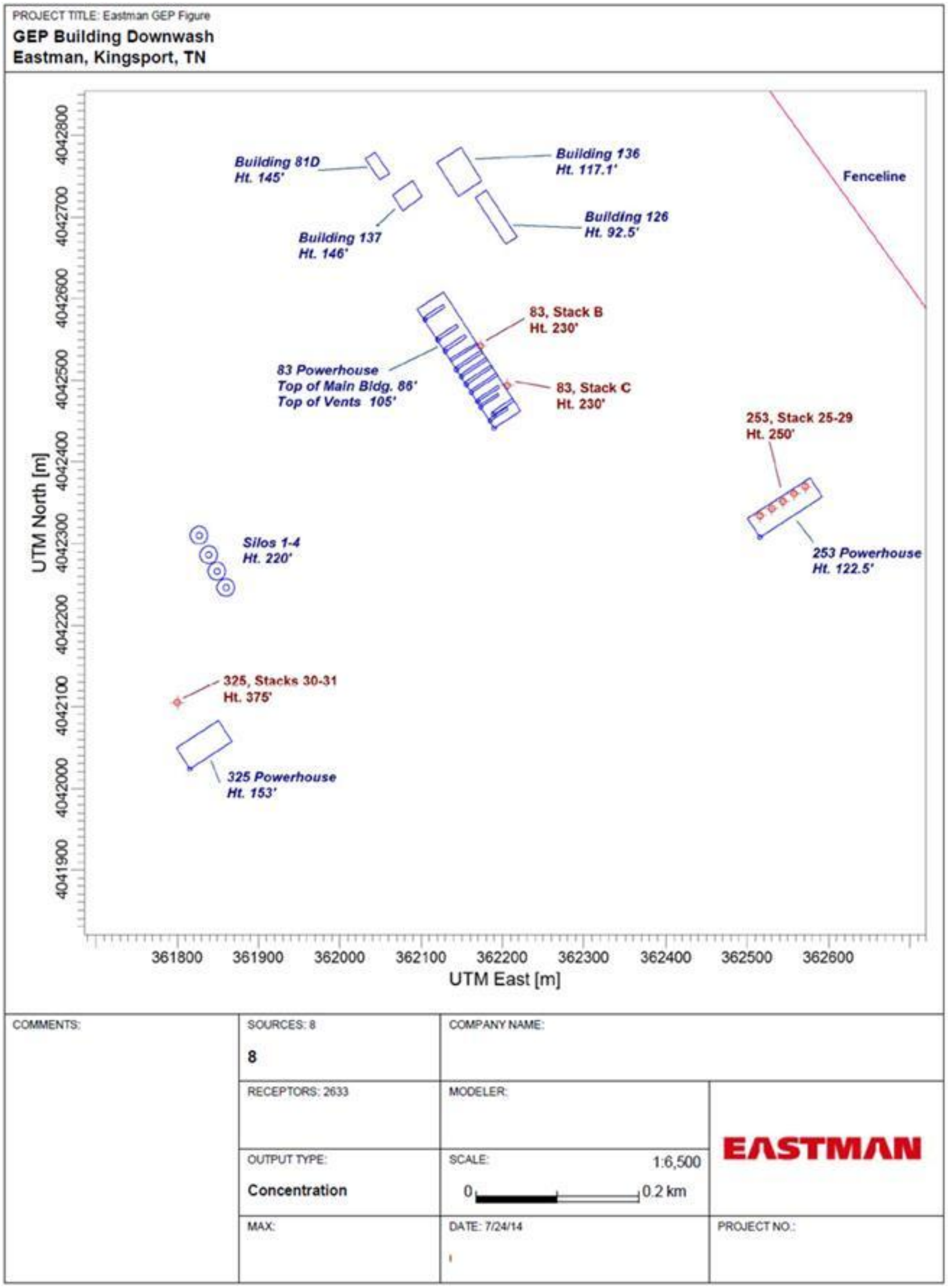
In the absence of influencing structures, a "default" GEP stack height is credited up to 65 meters.

A summary of the GEP stack height analyses is presented Table 7-1. The GEP formula stack heights for all the sources are higher than their respective stack heights. Therefore, emissions are potentially subject to building downwash and wind direction-specific building dimensions developed with the EPA's Building Profile Input Processor (BPIP-PRIME) were input to AERMOD. The BPIP input and output files are provided in the modeling archive. The locations and dimensions of the buildings/structures relative to the exhaust stacks are depicted in Figure 7-2.

**Table 7-1: Summary of GEP Analysis**

| Emission Source | Model Source Name | Stack Height (m) | Controlling Buildings / Structures | Building Height (m) | Projected Width (m) | GEP Formula Height (m) |
|---|---|---|---|---|---|---|
| 253 Powerhouse Sources | 253_25 – 253_29 | 76.2 | 253 Powerhouse | 37.3 | 116.8 | 181.2 |
| 325, Stacks 30-31 | 325_3031 | 114.3 | Silos | 67.1 | 69.0 | 149.1 |
| B-83 Powerhouse Stacks 18-22 | 83_1822 | 70.1 | B-83 Powerhouse (top of exhaust ducts) | 32.0 | 177.2 | 79.9 |
| B-83 Powerhouse Stacks 23-24 | 83_2324 | 70.1 | Building 81D | 44.2 | 177.9 | 113.7 |

**Figure 7-2: GEP Building Downwash for Eastman Chemical**



## 7.3 Evaluation Results for Default AERMOD

AERMOD was run using the default meteorological and modeling options in both AERMET and AERMOD, respectively. As noted, on-site meteorological data were processed up to 500 m to best capture the conditions observed by the $SO_2$ monitors. The hourly seasonal ambient background value was included in these model runs. For comparison to observed monitor data, three separate AERMOD runs were performed on a single receptor situated and processed at each the three monitors (Figure 3-1). Furthermore, to better estimate the actual impacts, hourly emission data (including stack temperature and exit velocity) for all eight sources were included in the modeling. The modeling and observation periods were coincidental, from April 1, 2012 through March 31, 2013.

The observed and predicted design concentrations for 1-hour $SO_2$ are tabulated in Table 7-2. Figure 7-3 plots these results, but also includes the model-to-monitor ratios for each site. As noted in section 5.2, an ideal unbiased model would produce values between 0.9 to 1.1. For the default case, the ratio values range between 1.8 to 2.7 (over-prediction). From a comparison of these three pairs of design values, it appears that AERMOD version 14134 run using the default options is producing unrealistic over-predictions. Examining the year-long time series of the daily maxima for each monitor, (Figures 7-4, a-c), we find that the default AERMOD model (in red) is producing an exaggerated and highly variable sequence of ground concentrations compared to the observed values (in blue), particularly at the elevated terrain of Skyland Drive.

The Q-Q plots (Figures 7-5, a-c) for each monitor also shows this over-prediction, with all ranked values shown. For the flat terrain monitors (Meadowview and Ross N. Robinson), the ranked predictions are about twice the observed ranked values. The performance of the default AERMOD is even worse at the elevated terrain Skyland Drive monitor (Figure 7-5c). The over-prediction of the model approaches a factor of 3.

For the flat terrain monitors, the top 10 observations occur during the daytime hours with relatively low wind speeds and convective mixing heights of at least 400 m. All but one of the predicted top 10 flat terrain concentrations occur during the daytime, but all occur in low wind surface conditions. Additionally, the convective mixing heights were generally below 400 m, with most occurring below 250 m. For Skyland Drive, the top 10 observations were mostly during daytime hours, with 2 nighttime hours also included, in low to moderate wind speeds. The predicted top 10 values, on the other hand, all occurred at night or early morning in low wind speeds conditions.

**Table 7-2: Comparison of 1-hour $SO_2$ Design Concentrations, Observed vs. Predicted (for the Default AERMET/AERMOD, version 14134)**

| April, 2012 – March, 2013 | H4H Concentrations (µg/m³) | |
|---|---|---|
| **Monitor** | **Observed** | **Predicted (Default)** |
| Meadowview | 359.5 | 730.5 |
| Ross N. Robinson | 428.1 | 776.0 |
| Skyland Dr. | 406.6 | 1102.8 |

**Figure 7-3: Comparison of Observed vs. Predicted 1-hour SO2 Design Concentrations for the Default AERMET/AERMOD, version 14134**

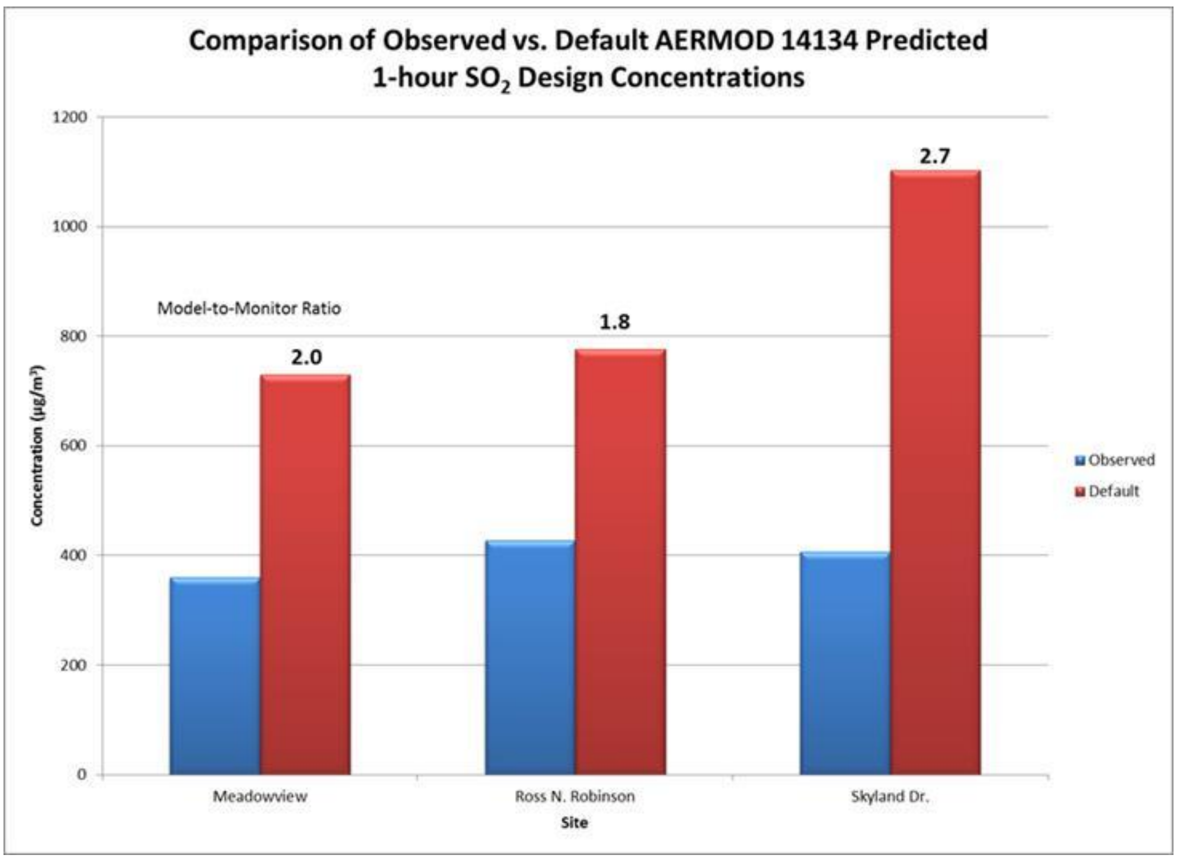


**Figure 7-4 (a-c): Time series of Daily Maxima of Observed (Blue) vs. Predicted (Red) for Default AERMOD, at (a) Meadowview, (b) Ross N. Robinson, (c) Skyland Drive**

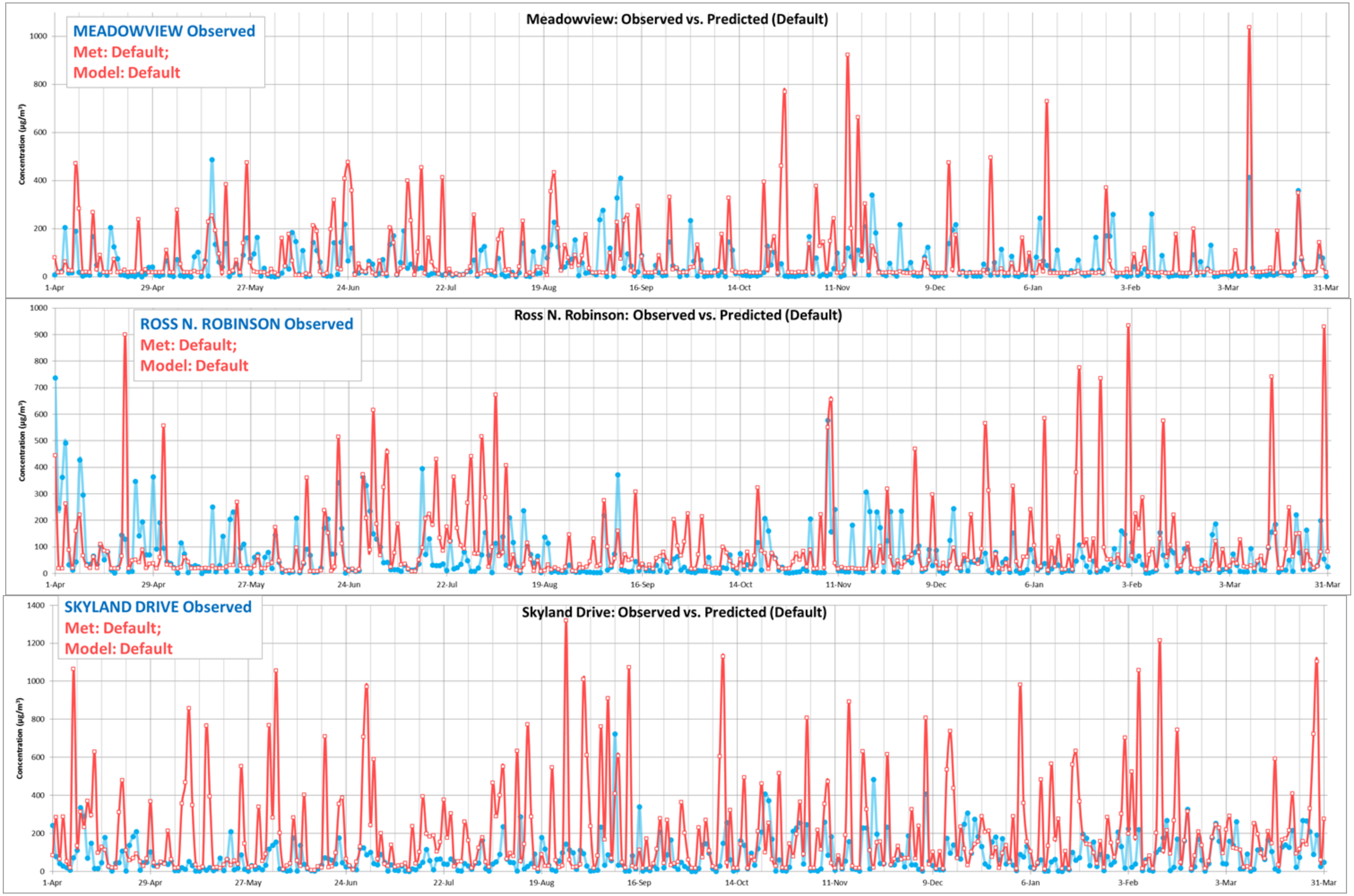
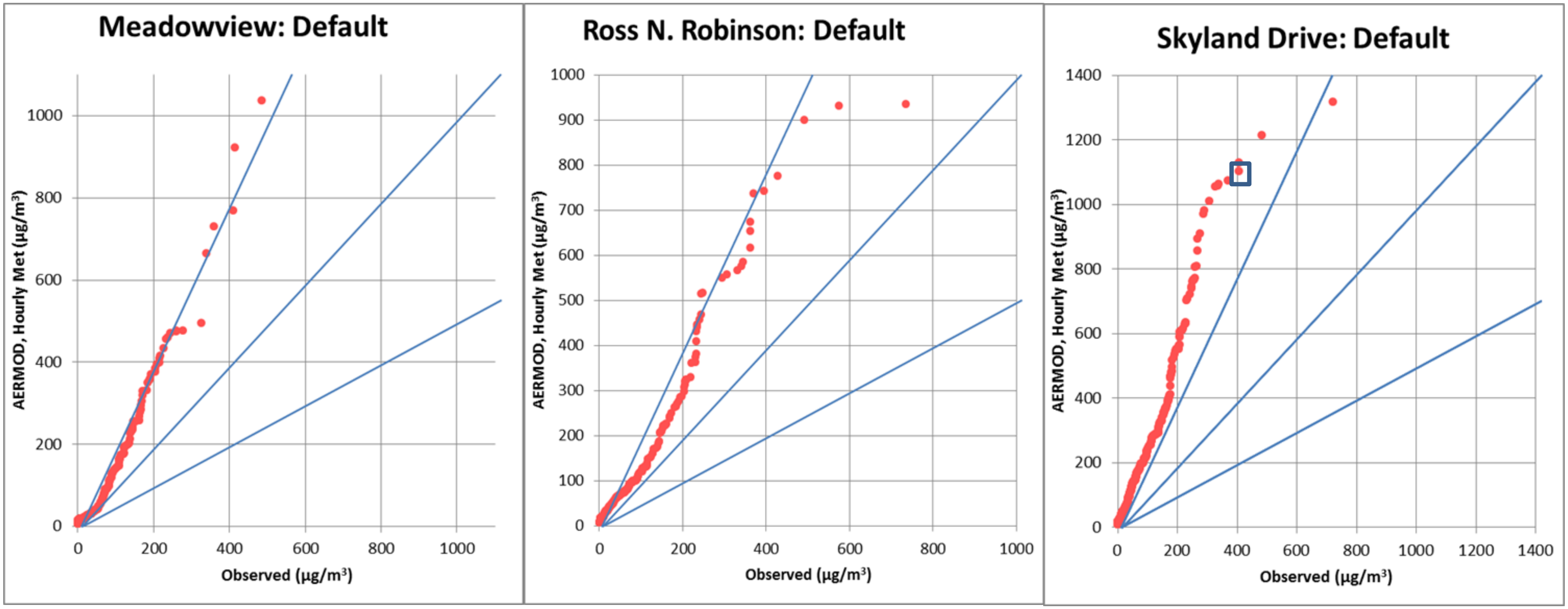


**Figure 7-5 (a-c): Q-Q Plots for Observed vs. Predicted Default AERMET/AERMOD version 14134**




(a) (b) (c)

*Notes:*

[1] *The upper diagonal shows the two-fold model over-prediction and the lower diagonal, the two-fold under-prediction. The central diagonal is the 1:1 correlation line.*

[2] *The predicted model concentrations include the seasonal by hour-of-day background value.*

[3] *The boxed value represents the design concentration (i.e. the High-4th-High)*

# 8.0 Formulation of Eastman's Site-Specific Dispersion Model

The need for a nearly unbiased site-specific dispersion model for the resolution of the Kingsport $SO_2$ nonattainment area led Eastman to ask AECOM to provide recommendations for enhancements to AERMOD based upon scientifically-justified principles. This section describes the formulation of "EASTMOD", the site-specific dispersion model based upon AERMOD that Eastman proposed to use for its Kingsport, TN facility.

## 8.1 Provisions for Acceptance of an Alternative Site-Specific Model

Appendix W, EPA's modeling guidance, has provisions for obtaining agency acceptance of an alternative model in the event that the default model is not adequate for the intended purpose. The applicable Appendix W language (Section 3.2.2(b)(2)) is provided below with *italics* applied to the specific case of interest here.

> 3.2.2 Recommendations
>
> a. Determination of acceptability of a model is a Regional Office responsibility. Where the Regional Administrator finds that an alternative model is more appropriate than a preferred model, that model may be used subject to the recommendations of this subsection. This finding will normally result from a determination that (1) a preferred air quality model is not appropriate for the particular application; or (2) a more appropriate model or analytical procedure is available and applicable.
>
> b. An alternative model should be evaluated from both a theoretical and a performance perspective before it is selected for use. There are three separate conditions under which such a model may normally be approved for use:
>
> > (1) If a demonstration can be made that the model produces concentration estimates equivalent to the estimates obtained using a preferred model;
> >
> > *(2) if a statistical performance evaluation has been conducted using measured air quality data and the results of that evaluation indicate the alternative model performs better for the given application than a comparable model in Appendix A;* or
> >
> > (3) if the preferred model is less appropriate for the specific application, or there is no preferred model. Any one of these three separate conditions may make use of an alternative model acceptable. Some known alternative models that are applicable for selected situations are listed on EPA's SCRAM Internet Web site (subsection 2.3). However, inclusion there does not confer any unique status relative to other alternative models that are being or will be developed in the future.
>
> b. The Regional Office should always be consulted for information and guidance concerning modeling methods and interpretations of modeling guidance, and to ensure that the air quality model user has available the latest most up-to-date policy and procedures. As appropriate, the Regional Office may request assistance from the Model Clearinghouse after an initial evaluation

and decision has been reached concerning the application of a model, analytical technique or data base in a particular regulatory action.

For this application using Appendix W Section 3.2.2(b)(2), we provide a description of the proposed EASTMOD model with citations to applicable technical references in this section. In the next section, we provide an evaluation of EASTMOD and compare the evaluation results to AERMOD (default).

## 8.2 Areas of Enhancement Incorporated into EASTMOD

It is evident from the evaluation results of AERMOD (default) that peak predictions occur in light wind conditions for the three monitors included in the Eastman evaluation. AECOM pursued model enhancements in two areas:

- Low wind speed improvements already being considered by EPA and implemented as beta options in AERMOD version 14134 were adopted in EASTMOD, with slight variations and enhancements.
- The merging of plumes from nearby stacks is not accounted for by AERMOD, but is probably occurring at Eastman, especially in light wind conditions.

The formulation of these two areas of enhancement into AERMOD to create the EASTMOD model is described in the following subsections.

## 8.3 Low Wind Speed Enhancements

In 2005, the EPA promulgated the currently recommended short-range dispersion model, AERMOD, which replaced the Industrial Source Complex (ISC) model as the preferred prediction tool for short-range dispersion applications. Over several years of AERMOD use, it has become apparent to the modeling community that peak predicted concentrations from AERMOD modeling can occur for simulated periods of low wind speeds. A review of the AERMOD evaluation databases noted above would indicate that there was not a significant focus upon data sets featuring low wind speeds.

In 2010, the results of a model evaluation study[24] sponsored by the American Petroleum Institute (API) and the Utility Air Regulatory Group (UARG) were provided to EPA that specifically examined the model's ability to predict under low wind speed stable conditions for near ground-level releases. The 2010 API/UARG sponsored study examined two aspects of the model: (1) the meteorological inputs, as it related to friction velocity ($u_*$) and (2) the actual dispersion model itself, especially the minimum lateral turbulence (as parameterized using sigma-v) assumed by AERMOD. As part of phase 1 of the study, Paine et al.[15] concluded that evaluation indicated that in low wind conditions, the $u_*$ formulation in AERMOD under-predicts this important planetary boundary layer parameter. The outcomes of this under-prediction in $u_*$ were too low and restrictive mechanical mixing heights, as well as underestimates of the effective dilution wind speed and turbulence in stable conditions. As part of phase 2 of the study, Paine et al.[15] concluded that the minimum sigma-v was too low by at

[24] Paine, R.J., J.A. Connors, and C.D. Szembek. AERMOD Low Wind Speed Evaluation Study: Results and Implementation. Paper 2010-A-631-AWMA, presented at the 103rd Annual Conference, Air & Waste Management Association, Calgary, Alberta, Canada. 2010.

least a factor of 2. These findings were consistent with those of Sykes et al.[25] with applications of SCIPUFF using a minimum sigma-v of 0.5 m/s with good modeling performance and Hanna[26] with reviews of low wind speed databases, who mentions a small turbulence scale sigma-v of 0.5 m/s as a typical value in low winds. A minimum sigma-v of 0.5 m/s in AERMOD (using LOWWIND2) in conjunction with the AERMET low wind speed beta u* option was reported by Paine[27] at the 2014 EPA modeling workshop to provide improved model performance for tall stack releases.

The result of the 2010 API/UARG sponsored study confirmed what the modeling community and EPA suspected, that AERMOD was significantly over-predicting modeled concentrations under low wind speed stable conditions.

EPA implemented improvements[28] to AERMOD similar to those suggested by Paine et al.[15] in its release of versions 12345, 13350, and the current release, 14134. In these releases, EPA implemented a correction to the friction velocity calculation in AERMET and also incorporated changes to the meander fraction calculation and the minimum sigma-v calculation in AERMOD.

Consistent with these available improvements to AERMET and AERMOD, the formulation of EASTMOD applies the following enhancements:

- The AERMET version 14134 with the beta u* option is used. The use of this beta option is consistent with encouraging evaluation results reported by EPA in its presentation[29] on version 13350 and the webinar recording[30] conducted on January 14, 2014.
- AERMOD with the LOWWIND2 option deployed and with a minimum sigma-v averaging 0.5 m/s, but split between 0.6 m/s for stack emissions in stable conditions and 0.4 m/s for emissions in unstable conditions. This implementation required a minor code change to AERMOD version 14134 to implement the stable/unstable "split" in the minimum sigma-v settings.

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[25] Sykes, R.I., S. Parker, D. Henn and B. Chowdhury, 2007: SCIPUFF Version 2.3 Technical Documentation. L-3 Titan Corp, POB 2229, Princeton, NJ 08543, 336 pp.; current SCICHEM documentation is available at http://sourceforge.net/projects/epri-dispersion/.

[26] Hanna, Steven R., 1983: Lateral Turbulence Intensity and Plume Meandering During Stable Conditions. *J. Climate Appl. Meteor.*, **22**, 1424–1430. doi: http://dx.doi.org/10.1175/1520-0450(1983)022<1424:LTIAPM>2.0.CO;2

[27] Presentation is available at http://www.cleanairinfo.com/regionalstatelocalmodelingworkshop/archive/2014/Presentations/Tues/012-aermod%20lowwind%20sensitivity%20and%20evaluation%20update%2023may14.pdf.

[28] See model update bulletins for descriptions of the improvements and technical references at http://www.epa.gov/ttn/scram/models/aermod/aermod_mcb8.txt and http://www.epa.gov/ttn/scram/models/aermod/aermod_mcb9.txt.

[29] Available at http://www.epa.gov/ttn/scram/webinar/AERMOD_13350_Update/AERMOD_System_Update_Webinar_01-14-2014_FINAL.pdf.

[30] Available at https://epa.connectsolutions.com/p166mjb0h19/?launcher=false&fcsContent=true&pbMode=normal.

## 8.4 Plume Merging Enhancements

The calculation of plume rise from one or more stacks is a key component in determining the downwind impacts associated with that source. Adjacent stacks of similar height and exhaust characteristics exist at numerous facilities, including Eastman for the 83 and 253 boiler complexes. Studies cited below refer to a study of actual field data of plume merging as well as wind tunnel studies that indicate that plumes from adjacent, aligned stacks tend to combine, resulting in a buoyant plume rise greater than that from any one of the individual sources. We find that implementing this concept as a post-processor to an initial run of AERMOD to determine effective hourly stack exhaust characteristics that accounts for the partial plume buoyancy merging will improve model performance.

## 8.5 Quantifying Enhanced Plume Rise from Adjacent Stacks

The tendency of adjacent stack plumes to merge is a function of several factors, including:

- the separation between the stacks,
- the angle of the wind relative to the stack alignment
- the plume rise for individual stack plumes (associated with individual stack buoyancy flux and meteorological variables such as stack-top wind speed).

In his "Plume Rise and Buoyancy Effects" Chapter 8[31], Briggs refers to the results of wind tunnel studies that indicate the usefulness of a merger parameter, S', to determine the effect of the angle of the wind relative to the stack alignment:

$$S' = [\Delta s \sin\Theta] / [L_B^{1/3} (\Delta s \cos\Theta)^{2/3}] \qquad \text{(Eq. 1)}$$

where

$\Delta s$ is the average spacing between the aligned stacks
$\Theta$ is the wind angle relative to the alignment angle of the adjacent, inline stacks
$L_B$ is the buoyancy length scale $= F_B / U^3$ (Eq. 2)
$F_B$ is the buoyancy flux $= g\, v_S{}^2 D_S{}^2/4\, (T_S - T_A)/T_S$ (Eq. 3)
U = the wind speed at plume height
$V_S$ = the stack gas exit velocity
$T_S$ = the stack gas temperature
$T_A$ = the ambient temperature
$D_S$ = the stack diameter

By definition, S' is undefined when the wind is exactly normal to the alignment angle, so in practice for that case, an angle of 89.99 is used in our implementation.

Briggs indicated that limited wind tunnel studies using neutral conditions showed that if S' is less than 2.3, then wind tunnel results indicate buoyancy enhancement, while values above 3.3 indicate no enhancement (intermediate values would indicate partial enhancement). However, Anfossi[32]

[31] Briggs, G. A. Chapter 8 in In *Atmospheric Science and Power Production*. D. Randerson (ed.), DOE/TIC-27601, U.S. Department of Energy.
[32] Anfossi, D., 1985. "Analysis of Plume Rise Data from Five TVA Steam Plants", *Journal of Climate and Applied Meteorology,* vol. 24, pp 1225-1236.

examined multiple cases of plume merging observed in the field at five Tennessee Valley Authority facilities with aligned stacks for both stable and unstable conditions. With this unprecedented large database, he reviewed a wide range of observations taken during the transitional and final plume rise under neutral and stable conditions. Our review of his findings indicates that the threshold values for buoyancy enhancement as a function of wind angle should be such that enhancement likely always occurs for S' less than 5, may not occur for S' above 10, and can be linearly scaled for S' between 5 and 10.

For those wind angles that allow plume merging, a formulation for the buoyancy enhancement accounting for other factors noted above due to the merging of adjacent plumes can be taken from Manins implementation[33] of Briggs formulation:

Buoyancy enhancement factor $E = [n+S]/[1+S]$ (Eq. 4)
where n = the number of stack in the row, and

S is a separation factor $= 6\ \{[(n-1)\ \Delta s]/[n^{1/3}\ \Delta h]\}^{3/2}$ (Eq. 5)
where $\Delta h$ is the plume rise for one stack.

## 8.6 Application of this Procedure

One way to define the parameters necessary for calculating the buoyancy enhancement on an hourly basis involves an initial run of AERMOD for the stacks involved. In order to extract the necessary data (i.e. the hourly and source specific final plume rise and effective wind speed), AECOM has created a modified version of AERMOD (version 14134) that extracts the necessary data using the DISTANCE-DEBUG option. To obtain data such as final plume rise that is used to compute effects of the plume merging process, we conduct this initial run on a 10-km ring of 360 receptors set 1° apart in flat terrain. A post-processor referred to as "AERLIFT" then takes the hourly meteorology and modeling data from the DISTANCE DEBUG output and determines whether plume merging occurs, and by how much (enhancement factor). The maximum enhancement factor applied to the buoyancy flux is the number of stacks in the line. The AERLIFT processor applies the enhancement factor to the original stack velocity and temperature and derives an altered set of parameters that increases the buoyancy flux by the appropriate factor, but preserves the momentum flux. This is done to conservatively apply the enhancement to only the buoyancy component. During stable hours, AERLIFT uses the plume rise directly in equation 5. For added degree of conservativeness, during unstable hours for when the stack top is less than the mixing height, AERLIFT selects the minimum between the final plume rise and the mixing height (which is defined as the maximum of the mechanical and convective mixing heights) for use in equation 5. The recalculated hourly emission parameters are then saved into a separate hourly emission file to be used in a second run of AERMOD.

## 8.7 Example AERLIFT Case

Consider a line of 4 stacks that are 25 meters apart, each with a height of 70 m and a diameter of 5 m with an east-west alignment. If all 4 sources are active, then under ideal conditions, the effective

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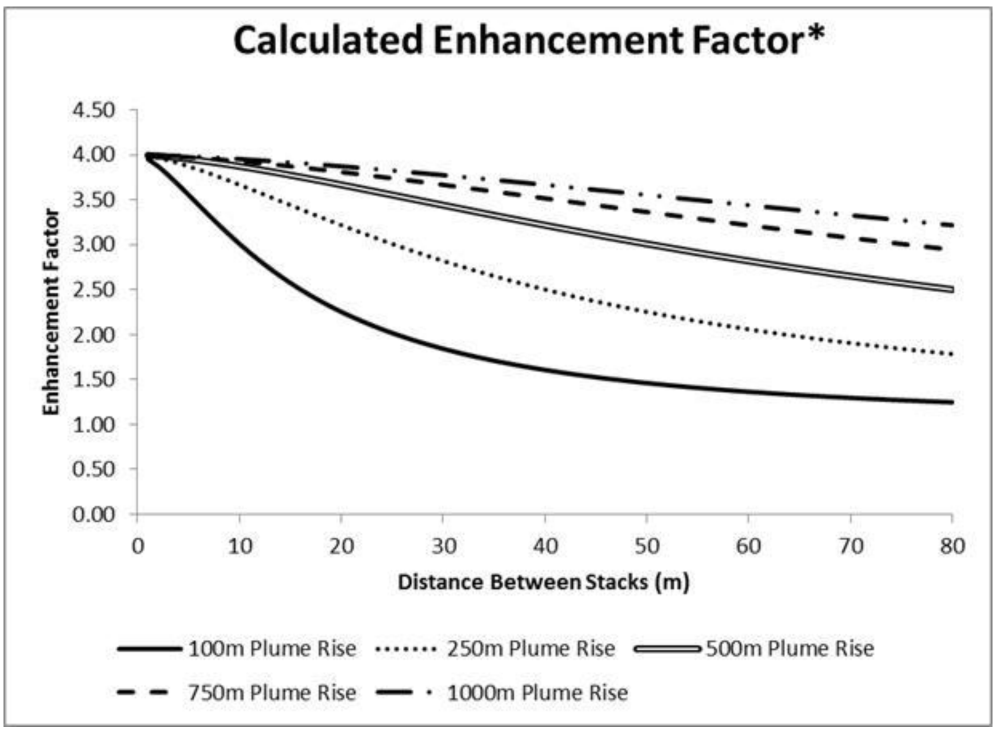
[33] Manins P, Carras J and Williams D, (1992), Plume Rise from Multiple Stacks. Clean Air (Australia). Volume 26, Part 2. pp 65-68.; see http://www.planning.nsw.gov.au/asp/pdf/08_0021_bamarang_ps_stage2_ea_app_c_pt3.pdf

merged buoyancy flux could be scaled up by a factor of 4. If the wind direction is not within 3 degrees of a normal direction (directly from the north or south), there is no effect on merging enhancement due to the wind angle effect; otherwise, there would be a scaled reduction. For most wind angles, Figure 8-1 displays the dependence of the enhancement factor on the distance between the stacks and the plume rise. Note that for very large plume rises (up to 1,000 m) the enhancement factor falls off slowly with increasing stack separation because the magnitude of the plume buoyancy results in substantial plume merging. In contrast, a weaker plume rise of only 100 m would result in a much faster fall-off of plume merging enhancement with stack separation, as shown in the figure. Note that for stacks with no separation, the result is full enhancement, as one would intuitively expect.

**Figure 8-1: Illustration of Buoyancy Enhancement for Adjacent Stacks**




* for most wind angles; if the wind blows exactly normal to the line of stacks, some reduction in this merging is expected, and the procedure accounts for it through the S' test.

## 8.8 Evaluation Tests Using EASTMOD

The modeling procedure with EASTMOD is somewhat more complicated than a standard run of AERMOD with default options because of the AERLIFT step that needs to be performed.

First, as mentioned in section 8.3, beta low-wind options were used in both AERMET (the adjusted u* option: METHOD STABLEBL ADJ_U*) and LOWWIND2 AERMOD option. As also mentioned in 8.3, the AERMOD version 14134 was enhanced to allow users, under the keyword LOW_WIND, to not only define the minimum sigma-v value, but to specify the minimum value for both stable and unstable conditions. Testing has shown that minimum values of 0.4 m/s for unstable and 0.6 m/s best approached observations at both the flat and elevated terrain monitors. The default values for the minimum wind speed (0.2828 m/s) and the meander fraction (0.95) were retained. The inputs were passed in as follows in the control card:

```
CO LOW_WIND  0.4  0.2828  0.95  0.6
```

Furthermore, this modified version of AERMOD (referred to here as “EASTMOD”) also included a customized debugging output option, DISTANCE-DEBUG, that extracts several key hourly plume parameters (including the final plume height, the wind direction and speed at final plume height) for use in the subsequent plume-merging post-processor, AERLIFT. After the DEBUGOPT keyword the DISTAN option (followed by the user supplied output file name) activates this debugging option:

```
CO DEBUGOPT DISTAN MV-Case1-MOD.dbg
```

EASTMOD needs to be run with hourly emissions (via the HOUREMIS keyword). The hourly emission file must also include hourly stack temperature and exit velocity. Finally, as noted in section 8.6, to determine the plume merging solely on the meteorology, EASTMOD is run on flat terrain with a 10km ring of 360 receptors set 1 degree apart.

The main output from this initial EASTMOD run is the DISTANCE-DEBUG output file. AERLIFT uses the hourly, source-specific plume data from the DISTANCE-DEBUG file in its plume merging calculations. Figure 8-2 shows a sample DISTANCE-DEBUG file, with the parameters used by AERLIFT highlighted. AERLIFT also requires the hourly ambient temperature (via the AERMET surface file) as well as the hourly stack temperatures and exit velocities (in the hourly emission file). AERLIFT initially calculates the alignment angle of the stacks that have been noted as being aligned. It should be noted that the current version of AERLIFT can only process one set of aligned sources at a time. Both the 253 and 83 powerhouses contain inline stacks (see Figure 7-3). Hence, first the 253 powerhouse sources and then the 83 powerhouse sources are processed.

Once the alignment angle for the sources is calculated, then AERLIFT proceeds through the hourly data by first assessing if the wind direction at plume height is conducive to plume merging. The angle between the wind direction and the alignment angle (from 0-90°) governs if, and by how much, buoyancy enhancement from plume-merging occurs. As mentioned in Section 8.5, S’ (eqn. 1) provides a measure of how much enhancement is allowed. Based on the Anfossi study, AERLIFT was run with S’ thresholds of 5 and 10, such that maximum possible enhancement could occur for S’ values less than 5, scaled between 5 and 10 and restricted for values over 10. If for a specific hour buoyancy enhancement is allowed, then the enhancement factor (eqn. 4) is calculated (capped by the number of aligned sources emitting at that hour). The enhancement is then applied to the hourly stack temperature and exit velocity. AERLIFT then produces a new hourly emission file with the enhanced hourly stack temperatures and exit velocities. For debugging purposes, AERLIFT produces a FluxInfo.txt file that contains the hourly intermediary variables used in assessing the enhanced buoyancy calculations.

The “AERLIFTed” hourly emission file is then used in a second and final run of Enhanced AERMOD using the same meteorology and modeling options as the initial Enhanced AERMOD run. Other key differences are that this second run is performed on the non-attainment receptors (see section 7.1) and includes the hourly seasonal ambient background (see Figure 8-3).

**Figure 8-2: Example Hourly Data from DISTANCE-DEBUG**

```
     OBSERVED MET CONDITIONS FOR:   USTAR   WSTAR  OBULEN  URB_OBULEN  ZIMECH  ZICONV   ZI_URB     SFCZ0   THSTAR
     YYMMDDHH: 12040102             (m/s)   (m/s)  (m)     (m)          (m)     (m)     (m)         (m)     (K)
                                     0.13   -9.00   12.90        N.A.  103.00 -999.00     N.A.    0.4280    0.090
    ------------------------------------------------------------------------------------------------------------

 POINT SOURCES:
    SOURCE        RCPT   FINAL  DIST.  WDIR  Effect. <------ DISTANCE -----> MEAND.  PART.   EFFECT. EFFECT.   HOURLY
POT.
    ID            NO.    PLUME  FINAL  FINAL WSPD    3600*      TO     PLUME FRAC.   PEN.    SIGMA_V SIGMA_W   CONC.       AERVAL COHERENT   PANCAKE  GAMFACT
PRMVAL      TEMP.
                         HT.    PL.HT  HT.           ueff       RECEPT TYPE          FRAC.
GRAD.
                         (m)    (m)    (deg)  (m/s)  (m/s)      (m)                          (m/s)   (m/s)     (µg/m3)     (µg/m3)   (µg/m3)    (µg/m3)
(µg/m3)  (K/m)
----------------------------------------------------------------------------------------------------------------------------------------------------------------
--------------
 P MERGE001        329  153.1   269.4  273.   2.669   9610.1    3242.0 GAU   0.025   0.000   0.200   0.052     35.017      0.000      0.000      0.000  PLUME OUT
OF WAKE  0.01637
   MERGEN01    <--- Source is not emitting during this hour
 P POINT002       1130   31.5   172.3  273.   1.347   4848.7 <  9157.9 GAU   0.090   0.000   0.200   0.074      2.209      2.209      2.422      0.066  PLUME OUT
OF WAKE  0.01637
 P POINT003        329   14.4   158.4  273.   1.347   4848.7    3202.3 GAU   0.073   0.000   0.200   0.074     13.187     13.019     14.021      0.330   1.000
13.187  0.01278
 P POINT004       1099   30.6   172.3  273.   1.347   4848.7 <  8260.8 GAU   0.085   0.000   0.200   0.074      2.880      2.880      3.141      0.055   0.000
6.682  0.01278
 P POINT005        325   16.2   158.4  273.   1.347   4848.7    2779.5 GAU   0.070   0.000   0.200   0.074     15.001     15.001     16.095      0.397   0.000
39.017  0.01278
 P POINT006        332   14.6   158.4  273.   1.347   4848.7    3637.3 GAU   0.077   0.000   0.200   0.074     14.365     14.365     15.528      0.358   0.000
24.576  0.01278
 P POINT007        333   15.6   158.4  273.   1.347   4848.7    3690.4 GAU   0.077   0.000   0.200   0.074     14.284     14.284     15.448      0.354   0.000
23.986  0.00781
```

**Figure 8-3: Seasonal by Hour of Day AERMOD Input**

```
** Seasonal Values **
** NOTE: First row of seasonal values below is for DJF
**            HOUR:   00    01    02    03    04    05    06    07    08    09    10    11    12    13    14    15    16    17    18    19    20    21
22    23
   BACKGRND SEASHR  1.31  0.79  0.26  0.92  1.57  3.14  1.31  1.57  1.05  2.10  1.57  5.50  2.88  2.62 14.93 10.74  2.36  8.65  3.93  7.60  1.31  1.57
1.31  1.05
   BACKGRND SEASHR  1.05  1.83  0.79  1.05  1.31  0.26  0.52  0.52  2.10  0.79  0.79 10.48  4.45 18.08  4.98  3.14  6.55  2.10  2.62  2.10  1.57  1.31
1.57  2.10
   BACKGRND SEASHR  1.05  0.26  0.26  0.26  0.26  1.31  0.26  0.26  1.05  1.57  4.19  2.88  7.07  6.29  3.67  3.67  3.93  2.36  3.14  2.62  1.57  1.57
1.05  0.26
   BACKGRND SEASHR  1.57  0.79  0.52  0.52  0.52  0.52  0.79  1.31  0.52  1.31  3.41  5.50  7.86 13.89 16.77 10.22  9.17  8.65  5.50  2.36  2.36  2.36
1.31  1.57

   BACKUNIT UG/M3
```

# 9.0 EASTMOD Results

EASTMOD, which includes Enhanced AERMOD and AERLIFT, was run using the on-site meteorological data processed with the adjusted $u_*$ low wind speed option in AERMET and the LOWWIND modeling option with the split minimum sigma-v explained in Section 8.8. The hourly seasonal ambient background value was included in these model runs. For comparison to observed monitor data, three separate AERMOD runs were performed on a single receptor situated and processed at each the three monitors (Figure 3-1). Furthermore, to better estimate the actual impacts from aligned sources (i.e. the sources at the 83 and 253 powerhouses), hourly emission data were processed through AERLIFT to credit a buoyancy enhancement associated with aligned sources. As with the default AERMOD runs, the EASTMOD and observation period were coincidental, starting from April, 2012 through March, 2013.

The observed and predicted (both default AERMOD and EASTMOD) design concentrations for 1-hour $SO_2$ are tabulated in Table 9-1. Figure 9-1 plots these results, but also includes the model-to-monitor ratios for each site. As noted in section 5.2, an ideal unbiased model would produce values between 0.9 to 1.1. For the default case (in red), the values range between 1.8 to 2.7 over-prediction. However, for EASTMOD (in green) these values range from 1.0 to 1.2 (the highest for Skyland Drive). From comparison of these pairs of design values, EASTMOD produces much more realistic predictions compared against those of the default AERMOD. Examining the year-long time series of the daily maxima for each monitor, (Figures 9-2, a-c), we note that the EASTMOD approach (in red) produces a sequence of ground concentrations that is both less sharply peaked than the default AERMOD output (Figure 7-5, a-c) and trends better against the observed values (in blue).

The Q-Q plots (Figures 9-3, a-c) for each monitor includes both the default AERMOD and EASTMOD results. For the flat terrain monitors (Meadowview and Ross N. Robinson), EASTMOD (in green) approaches the 1:1 correlation diagonal for not only the design concentration (i.e., the H4H), but down through the lower ranks compared to the default AERMOD (in red). Even though at the elevated terrain Skyland Drive monitor, EASTMOD over-predicts the design concentration, the overall performance of EASTMOD is a marked improvement over that of the default AERMOD results.

For the flat terrain monitors, the top 10 observations occur during the daytime hours with relatively low wind speeds and convective mixing heights of at least 400 m. The predicted top 10 observations also occur during the daytime in low wind conditions, but with convective mixing heights generally below 200 m. For Skyland Drive, the top 10 observations were mostly during daytime hours, with 2 nighttime hours also included, in low to moderate wind speeds. The predicted top 10 values, had a mixture of daytime and nighttime hours (more night than day) and a mix of low and moderate wind speeds.

**Table 9-1: Comparison of 1-hour $SO_2$ Design Concentrations, Observed vs. Predicted (for Default AERMOD and Site-specific EASTMOD)**

| Site | H4H Concentrations (µg/m³) | | |
|---|---|---|---|
| | | Predicted | |
| | Observed | Default | EASTMOD |
| Meadowview | 359.50 | 730.50 | 363.20 |
| Ross N. Robinson | 428.10 | 776.00 | 415.70 |
| Skyland Dr. | 406.60 | 1102.80 | 495.20 |

*April, 2012 - March, 2013*

**Figure 9-1: Comparison of Observed vs. Predicted 1-hour $SO_2$ Design Concentration**

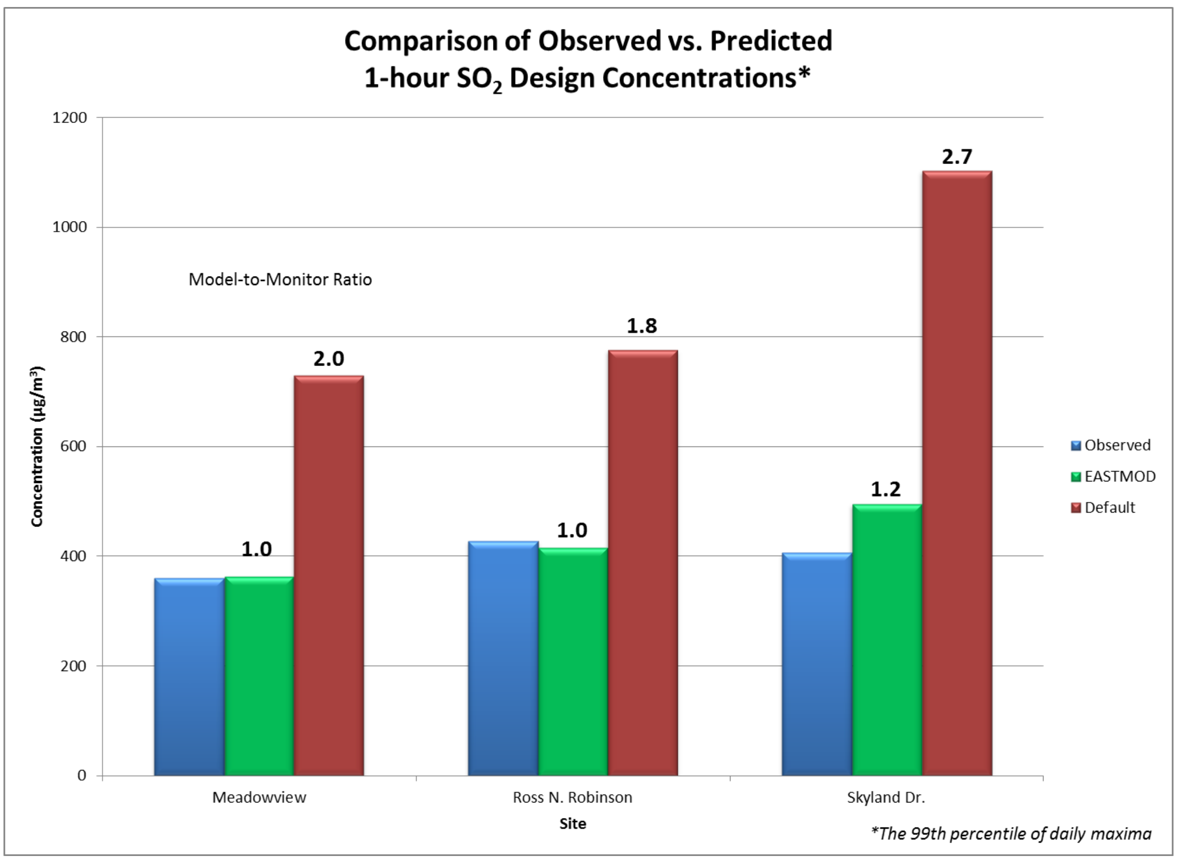


**Figure 9-2 (a-c): Time Series of Daily Maxima of Observed (Blue) vs. Predicted (Red) for EASTMOD, at (a) Meadowview, (b) Ross N. Robinson, and (c) Skyland Drive**

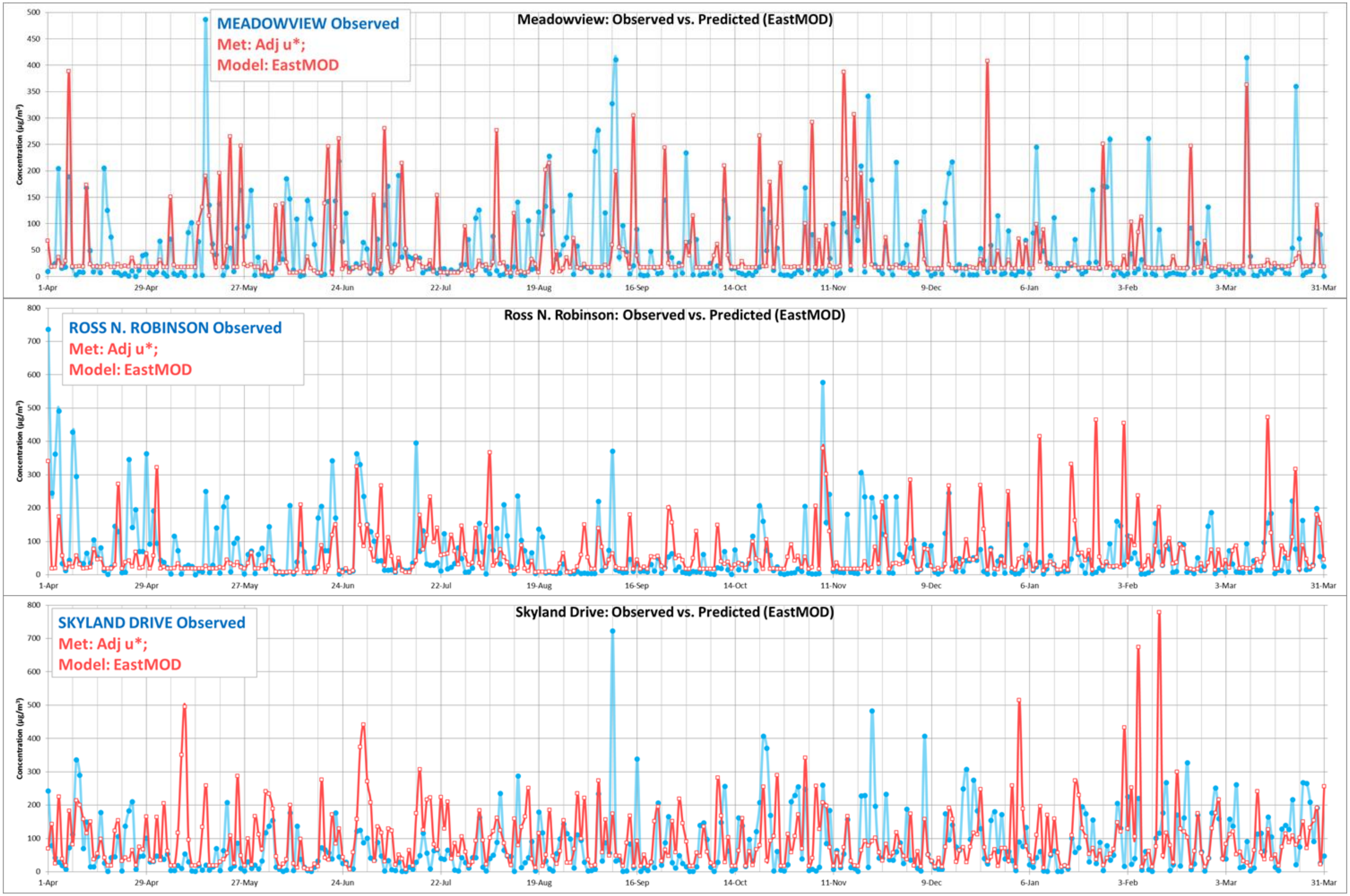
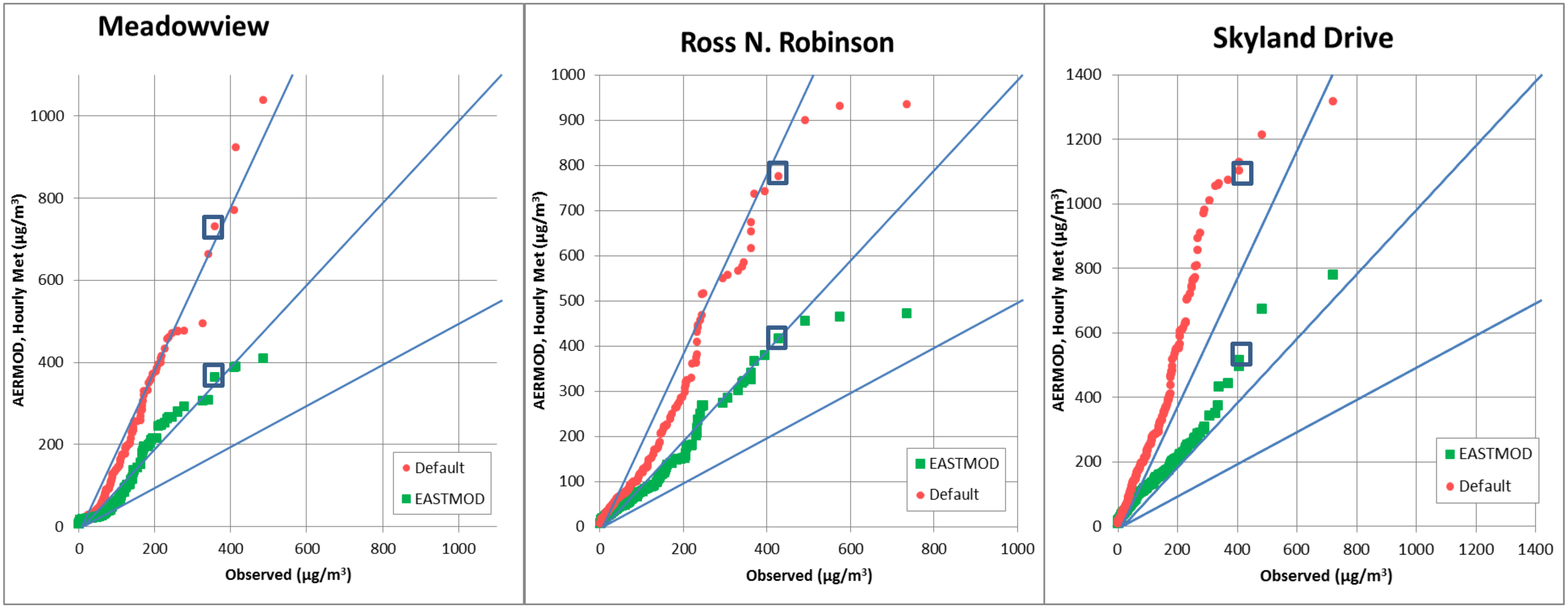


**Figure 9-3 (a-c): Q-Q Plots for Observed vs. Predicted**




(a) (b) (c)

*Notes:*

*[1]The upper diagonal shows the two-fold model over-prediction and the lower diagonal, the two-fold under-prediction. The central diagonal is the 1:1 correlation line.*

*[2] The predicted model concentrations include the seasonal by hour-of-day background value.*

*[3] The boxed values represent the design concentrations (i.e. the High-4th-High)*

# 10.0 Recommendations for Eastman Site-Specific Dispersion Model

The comparison of the performance of AERMOD (default) and EASTMOD clearly indicates that EASTMOD has better performance for this site. Furthermore, the evaluation results indicate an unbiased or over-predicting estimate of air quality concentrations at each monitoring site for EASTMOD. Therefore, use of EASTMOD is expected to be protective of air quality in the Kingsport area.

The formulation of EASTMOD is based upon the EPA-approved AERMOD model, but with scientifically justifiable enhancements, including:

- Improvements in the $u_*$ formulation in the AERMOD meteorological pre-processor;
- Use of a minimum sigma-v averaging 0.5 m/s in AERMOD, which is consistent with findings from other investigators and usage in other models such as SCICHEM;
- Accounting for partial merging of plumes from nearby stacks as computed on an hourly basis using algorithms reported in peer-reviewed technical publications.

Based upon these findings, Eastman and AECOM are providing TDEC and EPA with this documentation and all associated files for the modeling and the site-specific database that are required to completely replicate the model evaluation results. Model documentation for AERLIFT is also provided, as well as for the implementation of the "split" minimum sigma-v in AERMOD. All other aspects of the modeling are those used in normal AERMOD modeling applications.